Welcome to the Council on Forest Engineering(COFE)

Publications Website

2010. Fueling the Future
June 6–9, 2010. Auburn University Conference Center; Auburn, Alabama

Download the conference agenda here; or select an individual paper from the list below. If you know the last name of the primary author you may also click that letter below to go to that paper.

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Impact of Timber Sale Characteristics on Harvesting Costs

- Barrett, Scott M.; Bolding, M. Chad; Munsell, John F.; and Groover, Miles C.

  Characteristics of Logging Businesses Currently Harvesting Biomass for Energy in the Piedmont
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- Benjamin, Jeffrey G.; Mansius, Donald J.; and Read, Kate Albert

  Developing Woody Biomass Retention Guidelines in Maine

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- Burdg, Taylor and Gallagher, Tom

  Improved Skidding for Small Scale Biomass Harvesting Systems

- Cantú, Ricardo P. and LeBel, Luc

  How adequate are equipment replacement models for logging contractors?

- Carter,Emily A. and Thompson, Jason D.

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  Forest Biomass Assessment and Transportation Analysis for Evaluating the Feasibility of establishing a Biomass Power Plant in Northwest Oregon

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  Factors Associated with Logging Truck Accidents in Georgia; 1988-2008

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- Dodson, Elizabeth M.; Bolding, M. Chad; and Spong, Ben

  A Survey of Forest Engineering and Forest Operations Programs in North America

- Dodson, Elizabeth M.

  Some like it hot; some like it cold: Experience with biomass collection in western Oregon

- Dowling, Tripp N. and Bolding, M. Chad

  Trucking efficiency improvement through an analysis of in-woods turnaround times

- Dymond, Salli; Aust, W. Michael; Prisley, Steve; Eisenbies, Mark; Vose, James; and

Dolloff, Andrew

Forest Roads and Flooding

- Enrich, Andres; Greene, Dale; Baker, Shawn

  Status of Harvesting & Transportation for Forest Biomass– Preliminary Results of a National Survey of Logging Contractors; Procurement Foresters; Wood Dealers and Forest Managers

- Fairbrother, Simon; McGregor, Robert and Aleksandrov, Ivan

  Development of a Correlation Equation between Clegg Impact Values and California Bearing Ratio for In-Field Strength Assessment of Forest Road Subgrades

- Ford, William S. and Bolding, M. Chad

  Changes in Wood Procurement Strategies in Virginia: Coping with Market Volatility

- Garland, John J.

  Ideas Fuel the Future: The Changing Role of Forest Engineers and Foresters

- Gingras, Jean-Francois

  FPSuite: An Integrated Process Control Platform for Forestry Operations

- Grace III, J. McFero; Dougherty Mark; Carter, Emily; and Baharanyi, Ali

  Designing for effective evaluations of soil erosion and storm runoff

- Groover, Miles C.; Bolding, M. Chad; Conrad, Joseph L.; William S. Ford,; and W. Mike Aust,;

  Estimating Construction and Closure Costs of Minimum Standard Forest Roads; Bladed Skid Trails; and Water Crossings

- Hartsough, Bruce; Dempster, Peter; Gallo, Nicholas; Jenkins, Bryan and Tittmann, Peter

  Potential Improvements to Equipment and Processes for Harvesting Forest Biomass for Energy

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- Klepac, John and Rummer, Bob

  Harvesting Understory Biomass with a Baler

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  STUDY ON THE EFFECTS OF SHIFT SCHEDULE ON FOREST ENTREPRENEUR PERFORMANCE

- McDonald, T. and Rummer, B

Temperatures and sparking from operation of high-speed disk saws

- McDonald, T.P.; Haridass, K.; and Valenzuela, J.

  Mileage savings from optimization of coordinated trucking

- McKee, S.E.; Shenk ,L.A.; Bolding, M.C.; and Aust, W.M.

  Methods and costs of skidder and truck stream crossings in Virginia

- Meadows, Steven; Gallagher, Tom; and Mitchell, Dana

  Application of a Trailer-Mounted Slash Bundler for Southern Logging

- Mitchell, Dana and Elder, Tom

  Torrefaction? What's that?

- Robinson; T.J.; Via; B.K.; Tu; M.; Adhikari;S.; Fasina; O.; and Carter; E.

  Optimization of pyrolysis procedure for improved moisture resistance and reduced material costs in wood product manufacture.

- Rummer, Bob; Taylor, Steve and Corley, Frank

  Developing a New Generation of Woody Biomass Harvesting Equipment

- Sawyers, B. Clay; Aust, W. Michael; Bolding, M. Chad; and Wade, Charles R.

  Effectiveness and Costs of Five Skid Trail Closure Techniques in the Virginia Piedmont

- Sharma, Benktesh D; Wang, Jingxin; and Altizer, Clayton

  Modeling forest biomass in atmospheric carbon reduction in West Virginia

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  Woody Biomass Supply and Demand

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  Evaluating a Web Based Machine Productivity and Fuel Consumption Monitoring System

- Visser, Rien; Berkett, Hamish; Chalmers, Kent and Fairbrother, Simon

  Biomass recovery and drying trials in New Zealand clear-cut pine plantations

- Visser, Rien; Spinelli, Raffaele; Magagnotti, Natascia

  LANDING SIZE AND LANDING LAYOUT IN WHOLE-TREE HARVESTING OPERATIONS IN NEW ZEALAND

- Vitorelo, Brian; Han, Han-Sup

  Establishing a standard work sampling method for mastication operations analysis

- Vuki, George and Visser, Rien

  The effect of harvesting system on forest residue production in Fiji

- Wade,C.R.; Bolding,M.C.; Aust, W.M.

  Evaluation of Bladed Skid Trail Closure and Cover BMPs for Erosion Control

- Worrell, William C.; Bolding, M. Chad; and Aust, W. Michael

  COMPARISON OF POTENTIAL EROSION FOLLOWING CONVENTIONAL AND CABLE YARDING TIMBER HARVESTS IN THE APPALACHIAN PLATEAU REGION OF VIRGINIA

- Yoshimura, Tetsuhiko; Hartsough, Bruce

  VALIDATION OF A NEW CONCEPTUAL CABLE HARVESTING SYSTEM USING AN INDEPENDENT DEVICE FOR LATERAL YARDING

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“Fueling the Future”

COFE annual meeting
Auburn University
June 6 – June 9, 2010

Sunday, June 6 – Auburn University Conference Center

3:00 pm	Registration opens
6:00 – 8:00	Ice-breaker social, Conference Center Ballroom B (sponsored by Caterpillar)

Monday, June 7 – Auburn University Conference Center – Auditorium

7:00 am	Registration opens
8:00 am	Welcome – Dr. Jay Gogue, President, Auburn University Dr. Dick Brinker, Dean, School of Forestry and Wildlife Sciences Tom Gallagher, Annual meeting Chair
9:00 am	Keynote Speaker – Tom Kelly, retired logging engineer, Scott Paper, Mobile, AL - ***Logging practices from South Alabama – could they still apply?***
10:00 - 10:30	Break (sponsored by MeadWestvaco)
10:30 – 11:00	Bruce Narveson, Industry Manager, Forestry Division, Caterpillar Equipment Company, Lagrange, GA – CAT in the marketplace and new innovations for biomass.
11:00 – 11:30	Sam Houston, Manager of Supply Chain Services, Forest2Market - Biomass supply and demand.
11:30 – 12:00	Bryce Stokes, Senior Advisor, Navarro Research & Engineering Inc. – Role of Wood for Energy.
12:00 – 1:30	Awards Luncheon (sponsored by John Deere) Ballroom B
1:30 – 2:00	Doug Domenech, Secretary of Natural Resources, Virginia Commonwealth – How will the alternative energy market affect a southern state.
2:00 – 2:30	Tim West, Product Application Consultant, John Deere - What John Deere brings to the table.

2:30 – 3:00 Steve Taylor, Director, Center for Bioenergy and Bioproducts, Auburn University – Biomass to Liquid Fuel Conversion Technology

3:00 – 3:30 Break (sponsored by Caterpillar)

3:30 – 4:00 Bill Waller, Procurement Manager, Green Circle Bio Energy – From Wood to Energy.

4:00 – 4:30 How will the logger function in a biomass market? – Joseph Parnell, Parnell Logging, Maplesville, AL

4:30 – 5:00 John Garland – Professor Emeritus, Forest Engineering, Resources and Management, Oregon State University – Ideas fuel the future: the changing role of forest engineers and foresters.

6:00 – 7:30 Ice-breaker social, Conference Center Ballroom A

Monday Spouse/Guest Tour

10:00 am leave from Hotel for walking tour of campus

Noon back for awards luncheon

1:30 bus to June Collins Smith art museum

3:30 return

Tuesday, June 8 – Field trip

7:45 – 8:00 Leave from the front of the Conference Center at 7:45 am for several stops, followed by a social and evening meal at the Mary Olive Thomas tract south of Auburn (spouse transportation at 5:00 from Conference Center)

Biofuels Center
RMS roads and operations
AL Power Dare Park on lake – lunch and hear from AL Power
Logger visit

Wednesday, June 9 – School of Forestry and Wildlife Sciences Building
Concurrent Sessions

7:30 am Registration opens – School Conference Hall

Session A- Room 1221 – BMP's/Roads – moderator - John Fulton, Assoc. Professor, Biosystems Engineering, Auburn

8:00 – 8:20 Modeling Streamflow Responses to Road Density in the Coweeta Watershed, North Carolina - Salli Dymond, W. Michael Aust, Steve Prisley, Virginia Tech, Mark Eisenbies, Mississippi State, James Vose, and Andrew Dolloff, USDA Forest Service.

8:20 – 8:40 Designing for effective evaluations of soil erosion and storm runoff - J. McFero Grace III, Mark Dougherty, Emily Carter, and Ali Baharanyi, USDA Forest Service and Auburn University.

8:40 – 9:00 Development of a Correlation Equation between Clegg Impact Values and California Bearing Ratio for In-Field Strength - Simon Fairbrother, Robert McGregor and Ivan Aleksandrov, University of Canterbury.

9:00 – 9:20 Methods, BMP's, and costs of skidder and truck stream crossings in Virginia - Scott E. McKee, Luke Shenk, M. Chad Bolding, W. Mike Aust, Virginia Tech.

9:20 – 9:40 Estimating construction and maintenance costs of various standard forest roads and bridges - Miles C. Groover, M. Chad Bolding, and W. Mike Aust, Virginia Tech.

Session B- Room 1223 – Markets and Procurement - moderator – Tim McDonald, Assoc. Professor, Biosystems Engineering, Auburn

8:00 – 8:20 Changes in Wood Procurement Strategies in Virginia: Coping with Market Volatility - William S. Ford and M. Chad Bolding, Virginia Tech.

8:20 – 8:40 Hardwood Supply Logistics for Ethanol Production - Dr. Dalia Abbas, Dr. Ajit Srivastava, and Dr. Chris Saffron, Michigan State University.

8:40 – 9:00 Consequences of Mill Closures, Parcelization, and Wood-to-Energy Expansion for the U.S. South's Wood Supply Chain - Joseph L. Conrad IV and M. Chad Bolding, Virginia Tech.

9:00 – 9:20 Status of Technology for Harvesting Forest Biomass - Results of a National Survey of Logging Contractors and Industry - Andres Enrich, Jason Cutshall, Shawn Baker, and Dale Greene, University of Georgia, Amanda Lang and Brooks Mendell, Forisk Consulting LLC.

9:20 – 9:40 Characteristics of Logging Businesses Harvesting Biomass for Energy in the Virginia Piedmont - Scott M. Barrett, M. Chad Bolding, and John F. Munsell, Virginia Tech.

9:40 – 10:10 Break and poster session – School Conference Hall
(sponsored by International Paper)

Session C – Room 1221 – BMP's – moderator, Mathew Smidt, Assoc. Professor, School of Forestry and Wildlife Sciences, Auburn

10:10 – 10:30 Developing Woody Biomass Retention Guidelines in Maine - Jeffrey G. Benjamin, University of Maine, Donald J. Mansius, Maine Forest Service, and Kate Albert Read.

10:30 – 10:50 GPS and GIS Analysis of Mobile Harvesting Equipment and Sediment Delivery to Streams During Forest Harvest - Daniel Bowker, Jeff Stringer, Chris Barton, Songlin Fei, University of Kentucky.

10:50 – 11:10 Soil Disturbance and Site Impacts Related to a Thinning Operation in Kentucky - Emily A. Carter and Jason D. Thompson, USDA Forest Service.

11:10 – 11:30 Comparison of potential erosion following conventional and cable yarding timber harvests in the Appalachian Plateau - Bill Worrell, W. Mike Aust, and M. Chad Bolding, Virginia Tech.

11:30 – 11:50 Evaluation of Bladed Skid Trail Closure and Cover BMPs for Erosion Control - Charlie Wade, W. M. Aust, and M. Chad Bolding, Virginia Tech.

Session D – Room 1223 – System Design – moderator - Dana Mitchell, Research Engineer, US Forest Service

10:10 – 10:30 Potential Improvements to Equipment and Processes for Harvesting Forest Biomass for Energy - Bruce Hartsough, Peter Dempster, Nicholas Gallo, Bryan Jenkins and Peter Tittmann, UC – Davis.

10:30 – 10:50 Developing a New Generation of Woody Biomass Harvesting Equipment - Bob Rummer, USDA Forest Service, Steve Taylor, Auburn University, and Frank Corley, Corley Land Services.

10:50 – 11:10 Validation of a new conceptual cable harvesting system using an independent device for lateral yarding - Tetsuhiko Yoshimura, Shimane University and Bruce Hartsough, UC - Davis.

11:10 – 11:30 Some like it hot, some like it cold: Experience with biomass collection in western Oregon - Elizabeth M. Dodson, University of Montana.

11:30 – 11:50 The effect of harvesting system on forest residue production in Fiji - George Vuki, Rien Visser, University of Canterbury.

11:50 – 1:20 Business Luncheon and poster session – School Conference Hall (sponsored by Caterpillar)

Session E – Room 1221 – Productivity and Costs – moderator – John Klepac, General Engineer, US Forest Service

1:20 – 1:40 Are equipment replacement models adequate for Canadian logging contractors? - Ricardo P. Cantú & Luc Lebel, Laval University.

1:40 – 2:00 Impact of Timber Sale Characteristics on Harvesting Costs - Shawn Baker, Dale Greene, and Tom Harris, University of Georgia.

2:00 – 2:20 Evaluating a Web Based Machine Productivity and Fuel Consumption Monitoring System - Jason D. Thompson, John Klepac, USDA Forest Service.

2:20 – 2:40 Productivity and financial analysis of a field deployment of mobile pyrolysis for the in-woods production of bio-oil and biochar from forest treatment residues - Dr. Nathaniel Anderson, Dr. J. Greg Jones, and Dr. Woodam Chung, University of Montana and USDA Forest Service.

2:40 – 3:00 Establishing a standard work sampling method for mastication productivity analysis - Brian Vitorelo and Han-Sup Han, Humboldt State University.

Session F – Room 1223 – Safety and Environment – moderator – Bob Rummer, Project Leader, Forest Operations, US Forest Service

1:20 – 1:40 The effect of shift duration on the performance of forest harvesting operations - Luc Lebel, Laval University and Bruno Farbos, Montreal University.

1:40 – 2:00 Factors Associated with Logging Truck Accidents in Georgia, 1988-2008 - Jason Cutshall and Dale Greene, University of Georgia.

2:00 – 2:20 Modeling forest biomass in atmospheric carbon reduction in West Virginia - Benktesh Dash Sharma, Jingxin Wang, West Virginia University.

2:20 – 2:40 Discussion economy and energy balances of forest biomass utilization for Bio-energy at Sano city, Tochigi prefecture, in Japan - Kazuhiro Aruga, Ayami Murakami, Masashi Saito, Kaname Ito, Reiko Yamaguchi, Chikara Nakahata, Utsunomiya University.

2:40 – 3:00 Energy consumption of small scale production systems for fuel wood chips - Masahiro Iwaoka, Tsutomu Nakahara, Masayuki Ozawa, Akiyoshi Kanno, Yuta Inomata and Siaw Onwona-Agyeman, Tokyo University.

3:00 – 3:20 Break and poster session – School Conference Hall
(sponsored by Resource Management Services)

Session G – Room 1221 – Productivity and Costs – moderator - Dana Mitchell, Research Engineer, US Forest Service

3:20 – 3:40 A productivity and cost comparison of hog fuel production using slash forwarding and in-woods grinding of cured harvest - Dr. Nathaniel Anderson, Dr. Woodam Chung, Dr. J. Greg Jones, and Dan Loeffler , University of Montana and USDA Forest Service.

3:40 – 4:00 Productivity Estimates and Product Quality Measures for Chippers and Grinders on Operational Southern Timber Harvests - Addison Aman, Shawn Baker, and Dale Greene, University of Georgia.

4:00 – 4:20 Harvesting understory biomass - John Klepac, USDA Forest Service.

4:20 – 4:40 Optimizing the Use of a John Deere Bundling Unit in a Southern Logging System - Steven Meadows, Tom Gallagher and Dana Mitchell, Auburn University and USDA Forest Service.

4:40 - 5:00 FPSuite: An Integrated Process Control Platform for Forestry Operations - Jean-Francois Gingras, Program Manager, FPInnovations

Session H – Room 1223 – Transportation – moderator – Mathew Smidt, Assoc. Professor, School of Forestry and Wildlife Sciences, Auburn

3:20 – 3:40 Biomass recovery and drying trials in New Zealand clear-cut pine plantations - Rien Visser, Hamish Berkett and Kent Chalmers, University of Canterbury.

3:40 – 4:00 Trucking efficiency improvement through an analysis of in-woods turnaround times - Tripp N. Dowling and M. Chad Bolding, Virginia Tech.

4:00 – 4:20 Forest Biomass Assessment and Transportation Network Analysis for Evaluating the Feasibility of Establishing a Biomass - Joshua Clark, John Sessions, Michael Wing, Christian Schmidt, Oregon State University.

4:20 – 4:40 Mileage savings from optimization of coordinated trucking - McDonald, Haridass, Gallagher, Smidt, Valenzuela, Auburn University.

4:40 - 5:00 Estimating Crown and Understory Biomass in Operational Harvests of Roundwood and Biomass in Southern Pine Plantations - Addison Aman, Shawn Baker, and Dale Greene, University of Georgia

5:00 – Adjourn – The End

The Poster Session to be held all day Wednesday in conjunction with the coffee breaks and luncheon will include the following studies and possibly some late arrivals:

Effectiveness and Costs of Five Skid Trail Closure Techniques in the Virginia Piedmont - B. Clay Sawyers, W. Michael Aust, M. Chad Bolding, and Charles R. Wade, Virginia Tech.

Optimization of pyrolysis procedure for improved moisture resistance and reduced material costs in wood product - Robinson, T.J., Via, B.K., Tu, M., Adhikari,S., Fasina, O., and Carter, E., Auburn.

Improved Skidding for Small Scale Biomass Harvesting Systems - Taylor Burdg and Tom Gallagher, Auburn.

A Survey of Forest Engineering and Forest Operations Programs in North America - Elizabeth M. Dodson, M. Chad Bolding, Ben Spong, Virginia Tech.

Temperatures and sparking from operation of high-speed disk saws - McDonald, Rummer, Auburn.

Torrefaction? What’s that? - Dana Mitchell and Tom Elder, USDA Forest Service.

Injury Characteristics for Mechanized Logging Operations in the Southeastern US: 1996-2006 - Tal Roberts and M. Chad Bolding, Virginia Tech.

Landing size and landing layout in whole-tree harvesting operations in New Zealand – Rien Visser, Raffaele Spinelli and Natascia Magagnotti, Canterbury University.

FPSuite: An Integrated Process Control Platform for Forestry Operations - Jean-Francois Gingras, Program Manager, FPInnovations, Feric division, Pointe-Claire, Quebec, Canada H9R 3J9.

We anticipate allocating 15 hours of CFE's for this meeting (6 on Monday, 3 for Tuesday and 6 for Wednesday), but we are still awaiting approval.

Conference hotel: The Hotel at Auburn University, 241 S. College, Auburn, Alabama 334-844-4718. A block of rooms has been reserved at a rate of $96 per night (there is a lower rate for government employees). Ask for the annual COFE meeting.

Registration and Costs: (go to registration menu)

	Early registration	After April 30, 2010
COFE members:	$350	$450
Non-COFE members:	$400	$500
Students:	$200	$300
Spouse/Guest (all events):	$130	$180
Spouse/Guest Tour only:	$40	$50
One day (Mon or Wed): includes luncheon	$125	$150

Name:

Affiliation:

Address:

City, State, Zip:

Phone:

Email:

t-shirt size: S M L XL XXL

please check which events you plan to attend:

Sunday ice-breaker
Monday luncheon
Tuesday field trip
Wednesday luncheon

For any questions, please contact Tom Gallagher at tgallagher@auburn.edu or at 334-844-1095.

Council of Forest Engineers – The University of Auburn
June 06 – 09 2010

Hardwood Supply Logistics for Ethanol Production
Authors: Dalia Abbas, Ajit Srivastava, Christopher Saffron

Analyzing existing logging capacity is key to the improved understanding of the potential for starting up new biofuels conversion facilities. Supply chain logistics and analysis of hardwood species for ethanol production is under investigation. The objective of this investigation is to understand the economics and harvesting logistics linked to the start up of an ethanol facility in the eastern Upper Peninsula of Michigan.

In 2009 the State of Michigan received funds to complete a research and development study for the start up of the first wood to ethanol facility in the Upper Peninsula of Michigan. The research and development component analyses the life cycle, supply logistics, transportation, resource assessment, and the educational extension required to implement such a project. Both, the Michigan State University and the Michigan Technological University are carrying out the work.

The project Michigan State University titled Project III would be responsible for, which is the focus of this paper, analyzes the cost of supply systems and harvesting component of the study within 150 miles from the facility in question. We would be working to update the existing Forest Service model “Fuel Reduction Cost Simulator” with particular Michigan based conditions and up to date equipment status and to develop an inventory of existing equipment in this area. Further, a detailed survey was mailed out to loggers in the 150 miles surrounding the facility in question to link existing logging capacity with production potentials. Our study plans to detail the methods, cost analysis and type of technology involved in harvesting hard wood species in Michigan. Outcomes from the study include a set of different harvesting systems and scenarios, and a sensitivity analysis to identify the most sensitive variables to the supply of hardwood for ethanol production. Ethanol conversion technology, rates and methods will not be considered in the scope of this paper.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Productivity Estimates for Chippers and Grinders on Operational Southern Timber Harvests

Addison Aman, Graduate Research Assistant
Shawn Baker, Research Professional
Dale Greene, Professor

Center for Forest Business, Warnell School of Forestry & Natural Resources
University of Georgia, Athens, GA 30602-2152

ABSTRACT

Growth in bioenergy interests in the southeastern United States has created a need for cost-effective woody biomass harvesting systems. Three operational systems were evaluated for their potential production and cost: horizontal grinders fed with residue from roundwood harvests, horizontal grinders fed with residue from clean chipping harvests, and whole tree chippers fed entire stems. We evaluated three contractors operating each of the three system types over the course of one week each. Hourly production did not differ significantly between the three systems, but per ton costs were lower for the grinding operations than for the chipping operation. Hauling capacity and per acre volume removal were highly influential on costs.

INTRODUCTION

Renewable energy sources are receiving increased attention as more is understood about worldwide petroleum reserves, the threat of global warming from rising CO_2 levels, and energy security issues (Turner 1999). Renewable energy sources will no doubt play a vital role in shaping the economy of the future as fossil fuel prices rise. Biomass is one source of renewable energy that is being closely examined nationwide and particularly in the Southeast. In this context, biomass is defined as plant material that can be used to fuel other processes. The southeastern United States, with over 30 million acres of land dedicated to managed pine plantations, is the largest producer of forest products in the country. These forests have the potential to play a major role in producing biomass feedstocks for various industries.

The goal of this study was to study harvesting systems that can produce biomass feedstock in an efficient and economic manner. We examined systems that grind logging residues left behind after roundwood timber harvests (GRW) and after in-woods chipping systems that produce high quality chips for pulp and paper (GCC), as well as whole tree chipping systems that produce "dirty" chips (WTC).

METHODS

Site and Crew Characteristics – All of the crews visited in this study were operating in either Alabama or Georgia on loblolly pine (*Pinus taeda*) stands. Three different operations of each system type were observed for three to four days. Two of the WTC harvests were first thinnings while the third was a clearcut of a low-quality pine stand. Five of the grinder operations were following first thinnings, with the sixth, a GCC crew, following a clearcut. Pre-harvest inventories of stands to determine trees/acre and ton/acre estimates were not performed due to time and budget constraints.

Crew sizes varied by operation type, with grinding crews using one or two employees and WTC crews employing a larger crew to handle the harvesting functions (Table 1). One GCC crew used four employees during the study period to fell residual hardwood stems and feed them to the grinder. This was not a typical operation for that crew. Available trucking capacity varied between two and five trucks.

Table 1. Characteristics of forest biomass grinding and chipping systems in Georgia and Alabama studied during 2009-2010.

Crew Type	Crew Size	No. of Trucks	Chipper/Grinder
WTC	4	5	Morbark 50/48
WTC	5	4-5	Precision Husky WTC 2366
WTC	4	4	Morbark 30/36
GRW	1	4	Peterson 4710B
GRW	1	5	Vermeer HG 6000
GRW	2	3	Morbark 4600 XL
GCC	4	4	Peterson 4700C
GCC	2	4-5	Peterson 4700B
GCC	1	2	Morbark 3800

Time Study Techniques – Elemental time studies were performed at each of the sites that were visited. The studies typically lasted three to four days, or until approximately 30 truckloads were observed and recorded. Work sampling was conducted by recording the activity of each piece of equipment every two minutes throughout the day. These data were combined by harvest system type to calculate utilization rates and identify causes of delays. We grouped the delay categories into trucking related delays and non-trucking delays to assess the impact of available trucking on production. Work categories that were grouped under non-trucking delays include: waiting on trees/chipper/loader, mechanical delays, miscellaneous delays, and operational delays.

The time required to load each truck was recorded along with the length of any delays that prolonged the loading process. Total number of bites or swings of wood required to feed the chipper or grinder were also recorded. Mill scale tickets were used to record the weight of each load. This information was used to calculate average tons/scheduled machine hour (SMH) and tons/productive machine hour (PMH) for each of the three system types observed.

Cost Analysis – Two modified versions of the Auburn Harvest Analyzer were used to create cost estimates for grinder and whole tree chipping systems (Tufts *et al.* 1985) on a green ton basis. The assumptions that were used in the cost analysis of the grinding and chipping systems are available from the author.

RESULTS

Machine Utilization Analysis – Chipper/grinder utilization was the highest for WTC systems with a utilization rate of 44% (Figure 1). Both grinder systems had a slightly lower utilization rate of 38%. The utilization of the chipper/grinder could have been greatly increased if trucking related delays could have been avoided. These delays were the highest for the GRW and GCC systems with a rate of 49%.

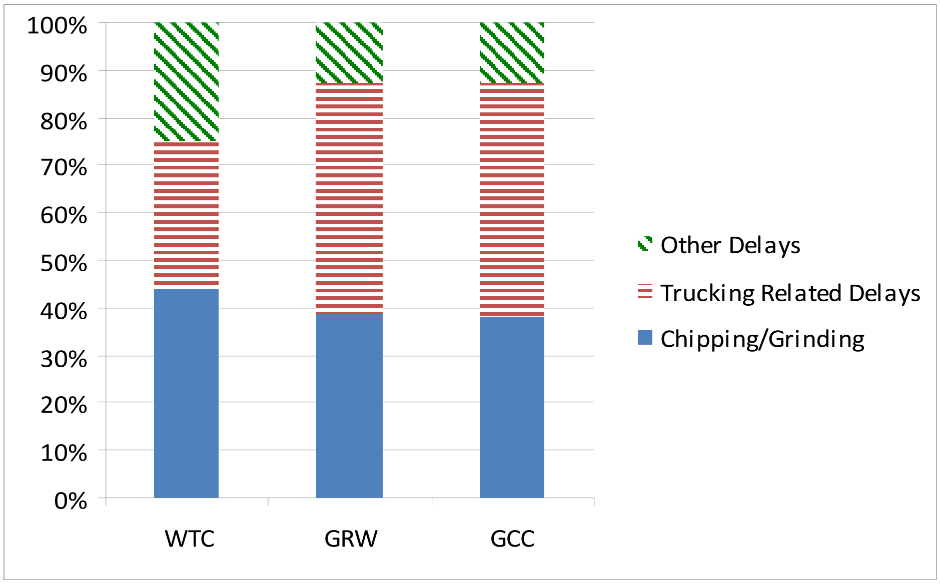

Figure 1. Utilization rates for chippers or grinders for each of the systems studied. Delays are categorized by trucking related and other delays.

While trucking related delays were not as significant for WTC systems, in this study chippers had more mechanical delays than grinder systems with a rate of 11%, compared to 4% for GRW crews and 9% for GCC crews (Figure 2). Overall, mechanical delays did not greatly reduce production for any of the systems studied.

Knuckleboom loaders were used by every system that was observed except for one GRW crew. On grinding crews they were typically teamed with front-end loaders that piled material within reach of the knuckleboom and loaded the chipper/grinder when possible. Knuckleboom loader utilization rates 42%, 32%, and 33% on the WTC, GRW, and GCC crews, respectively. Combined loading and piling utilization rates for front-end loaders on the GRW and GCC crews were 38% and 51% respectively.

Feller-bunchers and skidders were used by the WTC systems because harvests occurred concurrently with the chipping operation. Feller-buncher utilization was excellent with an average rate of 76% for the systems observed. Skidder utilization was a bit lower than the felling machine with a rate of 57%. Part of the reason for this is that most operations used more than one skidder, but we were only able to observe one of them given our manpower in the field. Therefore wood may have still been skidded to the deck even though the machine we were observing was idle/off.

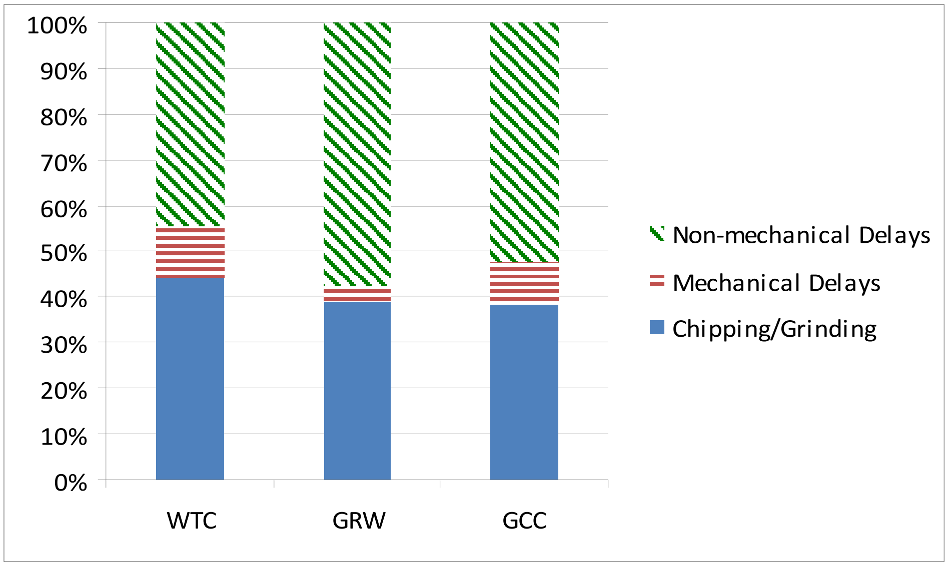

Figure 2. Utilization rates for chippers or grinders for each of the three systems studied. Delays are categorized by mechanical and non-mechanical delays.

Production Rate Analysis – We summarized the production rates for the three system types on both a potential production (tons/PMH) and observed production (tons/SMH) basis (Figure 3). Neither average production per SMH nor per PMH differed siginificantly between the three systems ($p > 0.05$).

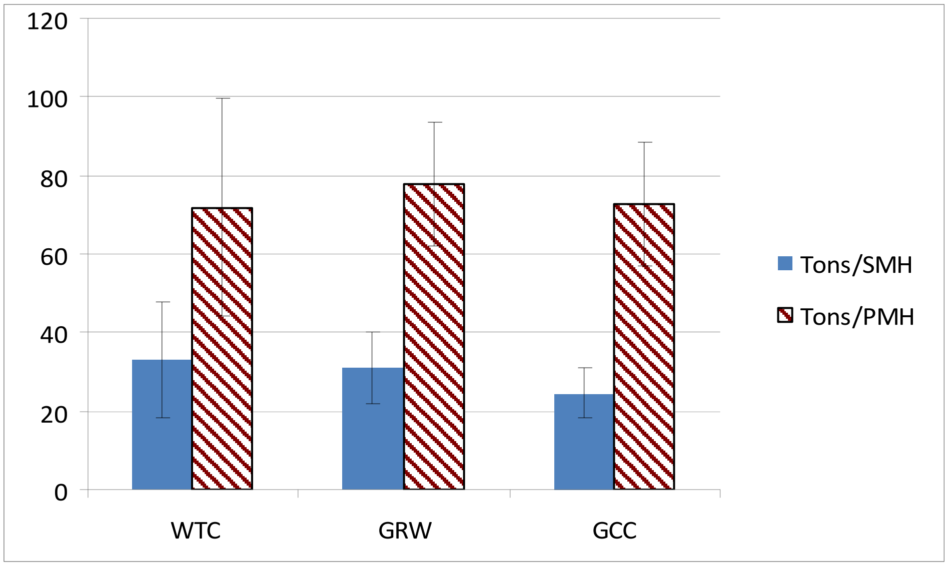

Figure 3. Comparison of tons/SMH and tons/PMH for the three forest biomass harvesting systems observed.

System Cost Analysis - Whole tree chipping systems had the highest calculated cost per green ton of delivered material with $21.26. The larger crew sizes needed to fell and extract trees for the chipper added substantial cost, particularly given the small diameter of felled stands (less than 8 inches DBH). Grinder systems had lower delivered costs per green ton with $21.18 for GCC operations and $20.25 for GRW operations. GCC operations required more effort on the part of both the knuckleboom and the front-end loader to accomplish the same production rate as the GRW operations, driving costs slightly higher.

Sensitivity analyses were performed on a variety of key inputs for each of the system models that were created. Ton per acre removals were examined for grinding and whole tree chipping systems separately because they differ drastically from one another. Removals between 3 to 15 tons/acre of residual material represent a typical range for the grinder operations that were observed. The delivered price per ton falls by $2.55 as the per acre removals increase to 15 tons (Figure 4). The same trend occurs for WTC systems over a typical removal range of 20 to 100 tons per acre (Figure 5). The delivered price decreases $1.65 as the removals increase to the maximum of 100 tons/acre.

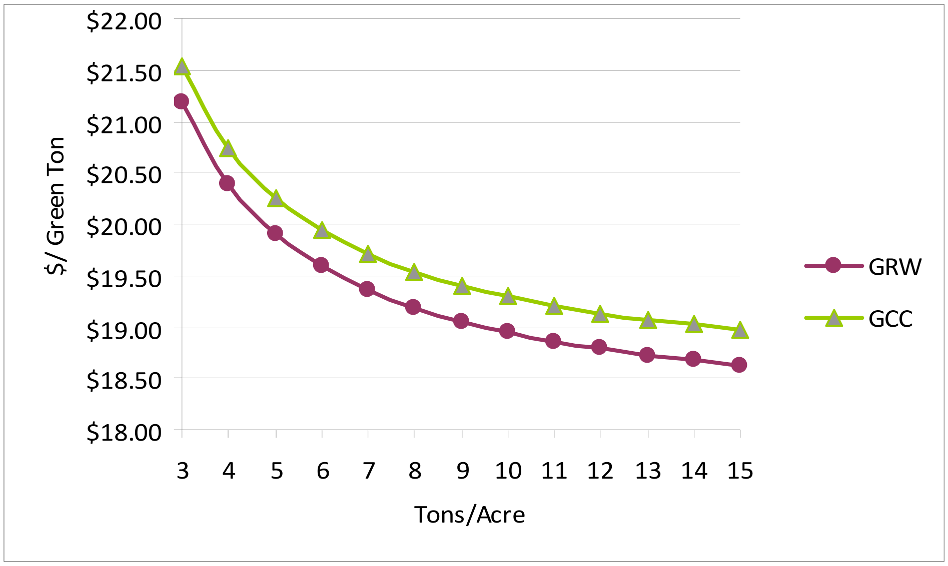

Figure 4. Delivered material cost estimates for increasing ton/acre removals for biomass harvesting systems using grinders and chippers.

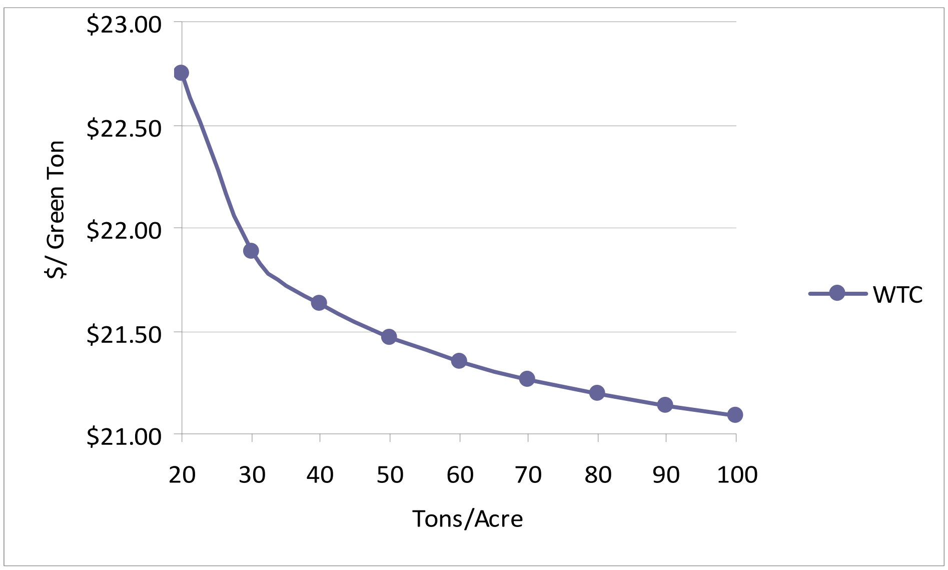

Figure 5. Delivered material cost estimates for increasing ton/acre removals for whole tree chipping systems

The limited availability of trucking caused increases in haul distances to have a very large effect on the delivered cost of material for each system type (Figure 6). As haul distance increases from 50 to 120 miles the delivered cost of material rises by $18.13 for WTC systems and $17.01 for grinder systems. Additionally, payload maximization is important to maximize trucking efficiency (Figure 7). Decreases in total payload cause substantial increases in delivered costs.

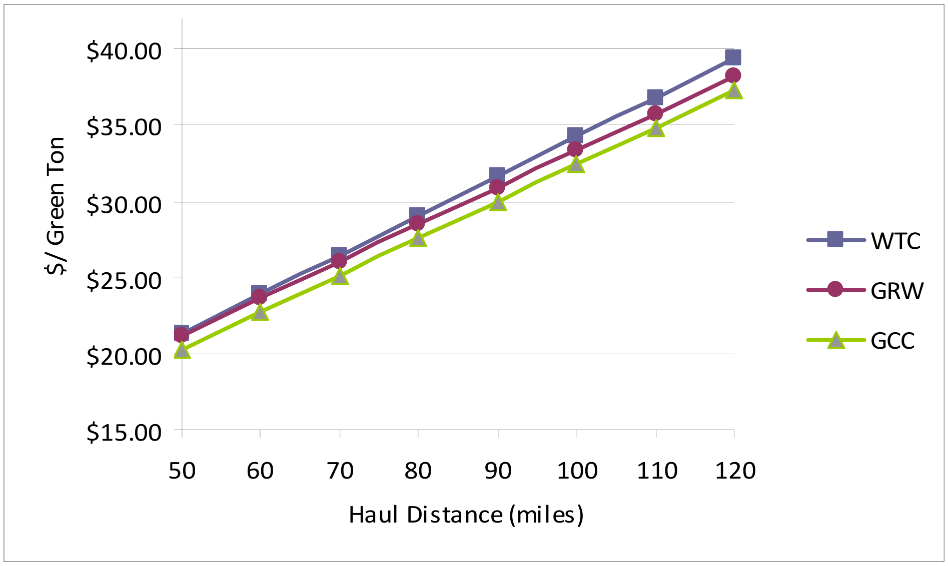

Figure 6. Delivered material cost for increasing haul distances (miles) for all 3 system types.

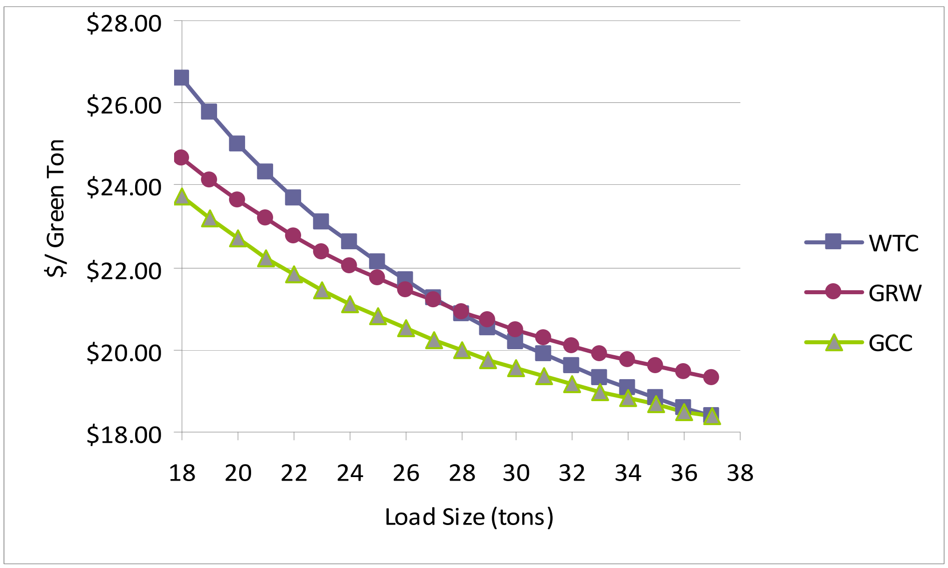

Figure 7. Delivered material cost for increasing truck load weights (tons) for all 3 system types.

CONCLUSIONS

All three systems showed relatively low chipping or grinding machine utilization during our study period. The availability of trucks was a major contributing factor in the grinding operations. While trucking was also a factor in the chipping operations, feller-buncher utilization averaged over 75%, suggesting that felling capacity is very close to limiting when using one feller-buncher to feed a full-sized chipper in the smaller stands typically being used for biomass-only harvests.

Productivity was statistically equal between the three systems, but the additional machinery and personnel needed to produce whole-tree chips drove the cost per green ton higher for the WTC crews. All three systems were sensitive to changes in trucking availability, payloads, and per acre tonnage removals.

ACKNOWLEDGEMENTS

This research was funded by a grant from the Georgia Traditional Industries program. The authors also wish to acknowledge the cooperation of all harvesting contractors in this project as well as Plum Creek Timber Company for their assistance.

LITERATURE CITED

Tufts, R.A., B.L. Lanford, W.D. Greene, and J.O. Burrows. 1985. Auburn harvesting analyzer. The COMPILER Forest Resources Systems Institute, Florence, AL. 3(2):14-15.

Turner, J. A. (1999). "A Realizable Renewable Energy Future." Science 285(5428): 687-689.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Estimating Crown and Understory Biomass in Operational Harvests of Roundwood and Biomass in Southern Pine Plantations

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ABSTRACT

Forest managers and wood suppliers need a method for assessing the amount of biomass available on potential harvest sites when harvesting plans and decisions are being made. We evaluated the utility of using variable-top, total and merchantable tree green weight equations for predicting crown biomass on operational harvests in southern pine stands. Stands at three locations in Georgia were inventoried prior to an operational thinning or clearcut. Roundwood and biomass amounts were estimated using the inventory data with appropriate weight equations. Actual tonnage of roundwood and biomass were monitored by product during the operational harvest. A post-harvest inventory was then performed to assess the residual stands after thinnings as well as any residual material left on the ground at each site. Pre-harvest estimates were compared to the sum of material harvested and remaining on site to assess the utility of this approach to accurately estimate biomass available for harvest in an operational setting.

INTRODUCTION

The ability to accurately predict the amount of biomass on a given tract is a significant problem that is currently facing the forest products industry. Standard timber inventories are designed to predict volumes or weights of traditional roundwood products (i.e. pulpwood, chip-n-saw & sawtimber) from the tree bole, and therefore leave out estimates of understory and crown biomass that have the potential for use in bioenergy markets. As markets for residual biomass mature, it will be important to have accurate predictions of the volume or weight of this material so stands of timber can be properly valued and to help match harvesting systems to appropriate sites.

Residual biomass can be either chipped or ground in woods and transported via truck to an end user. Currently most of this material is being hauled to forest products mills, which burn the wood in boilers to produce energy to fuel their processes. As more bio-conversion technologies become commercially feasible and are implemented on a large scale, the markets for this material will increase. Utilizing the residual biomass on a tract can increase the returns from the property, which is why it is important to have an accurate estimate of the volume.

One logical approach to predicting amounts of residual biomass is to use sets of equations that estimate tree weights to a range of merchantability standards (Avery and Burkhart 1994). These sets of equations generally include one equation that estimates the total weight of the entire tree (bole and crown) and other equations that estimate merchantable bole weights to different merchantable top diameter limits (Clark and Saucier 1990, Clark *et al.* 1986, Baldwin 1987, Harrison and Borders 1996). The bole weight estimate can be subtracted from the total tree weight estimate to provide a measure of the crown biomass (limbs and top) associated with the tree. Whole tree weight equations were used along with equations for predicting merchantable weights of loblolly pine (*Pinus taeda*) and slash pine (*P. elliottii*). The results of subtracting these various equations were compared with actual harvest amounts to see if they accurately described the amount of recoverable biomass.

METHODS

We selected a total of six stands for crown and understory biomass predictions. These stands represented the range of pine plantation sites owned by our industry partner, Plum Creek Timber Company, across the state of Georgia (Table 1). Loblolly pine was the planted species in each stand except for one site in Wayne County where slash pine was planted. All stands were being thinned during 2010 for the first time except for one stand in Randolph County that was clearcut due to poor stand conditions that justified replanting. Each stand had some level of hardwood competition as well as the planted pine species.

Table 1. Stand characteristics for six pine plantations used to compare methods of estimating crown biomass during 2010.

County (GA)	Pine Species	Age	Acres	Harvest Type
Putnam	loblolly	16	164	first thinning
Putnam	loblolly	18	106	first thinning
Wayne	slash	18	122	first thinning
Brantley	loblolly	18	57	first thinning
Randolph	loblolly	18	53	clearcut
Randolph	loblolly	18	52	first thinning

We performed an inventory in each of the six stands both before and after harvest to assess predicted and actual biomass removals. Fixed area (0.05-acre) circular plots were used to estimate standing timber on each site. Diameter at breast height (DBH) of each pine tree in each plot was measured along with the DBH of each hardwood stem that was at least 15 feet in total height. Hardwoods below that height were considered unlikely to be harvested by a feller-buncher during an operational harvest. We sampled 25 plots in each stand regardless of tract size due to time constraints. Plots were organized on a grid system that spaced them systematically across each tract. Several pines in each stand across the observed DBH range were also measured for total height using a clinometer. These sub-sampled total heights were used to calculate a regression of total height to DBH, so that pine heights on each site could be estimated. The heights of the hardwood species on each plot were estimated to the nearest foot at the time of inventory. The center of each plot was marked with flagging and the nearest tree that was likely to be left after harvest was flagged as well. A bearing and distance from the flagged tree was recorded so that the plot center could be relocated for the post-harvest inventory. A GPS point was also recorded as a final measure to ensure that the same plot could be re-inventoried following harvest.

Weights of standing pine stems were calculated using equations from Clark and Saucier (1990). Total tree weights (wood, bark, foliage) for pine were calculated for each tract as well as bole weights to a 4" top. We subtracted the calculated bole weights from the whole tree weights to estimate the crown weight of each tree. Standing hardwood stem weights were calculated using a total green weight equation for soft hardwoods in the Southeast (Clark *et al.* 1986). Actual harvest weights were obtained from Plum Creek harvest records for each study site. These were summarized by roundwood and biomass products to compare to the inventory estimates at each site.

Post-harvest protocol used the pre-harvest inventory techniques with the addition of line intersect sampling to account for material recorded as standing during the pre-harvest inventory but knocked down and left on site after harvest. This method of sampling has been used for years to estimate logging residue as well as fuel loading on forest sites (Warren and Olsen 1964). Our basis sampling methods can be found in Van Wagner (1968). Several 100-foot transects were laid across each stand and the diameters of each piece of green debris that each transect intersected were recorded into half-inch DBH classes. Estimates of downed biomass (tons per acre) for each of the stands were developed using the methods described by Borders and Shiver (1996).

RESULTS

Site conditions varied significantly for each of the six stands (Table 2). The two Randolph County sites each had 20 tons per acre or less of pine while having significant hardwood biomass (13-28 tons per acre). These inventory results support the decision to clearcut and replace one of these stands. The other four stands supported total biomass of 90 or more tons per acre prior to first thinning. Across all six stands, the most significant difference is the amount of hardwood tonnage available, ranging from 1.4 tons per acre in Wayne County to 28.8 tons/acre in Randolph County.

Harvests began on each of the six stands during the last half of 2009. However, weather and market conditions have continued to delay completion of the operations on the two Putnam County sites, so here we show results for the remaining four study sites (Table 3). Post-harvest estimates of down material were similar for each stand, ranging from 1.6 to 2.9 tons per acre. After thinning, the stand density ranged from 170 to 276 pine stems per acre with 18 to 78 tons of residual standing timber. On the Wayne and Brantley sites, there was little standing hardwood before harvest but most of it remained after harvest. Apparently there was so little of this material that the operation did not aggressively target it for removal.

Table 2. Pre-harvest stand density (trees/acre) and standing biomass (tons/acre) estimates for the six stands involved in the study.

County	Pine	Hdwd	Total	Pine Bole	Pine Crown	Hdwd	Total
	Trees per Acre			Green Tons per Acre			
Putnam	501	199	700	74.9	17.8	10.6	103.3
Putnam	642	85	728	89.2	16.3	2.5	108.0
Wayne	397	75	472	76.2	13.9	1.4	91.6
Brantley	499	137	636	107.7	19.5	1.6	128.8
Randolph	151	626	777	11.8	2.4	28.8	43.0
Randolph	235	395	630	20.1	4.0	13.1	37.1

Table 3. Post-harvest estimates of stand density (trees/acre) and standing and down biomass (tons/acre) for the four stands where operations are complete, May 2010.

County	Pine	Hdwd	Total	Pine Bole	Pine Crown	Hdwd	Down Material	Total
	Trees per Acre			Green Tons per Acre				
Wayne	177	99	276	43.0	7.9	1.1	2.0	54.0
Brantley	186	44	230	63.5	10.9	0.4	2.9	77.8
Randolph	0	0	0	0	0	0	2.4	2.4
Randolph	130.4	40	170	11.6	2.3	2.4	1.6	18.0

Predicted and observed biomass removals were compared for each of the four completed harvest sites (Table 4). Pine bole and biomass chip weights harvested from each stand were recorded by Plum Creek in their wood accounting system and were used to calculate per acre tonnages. Predicted biomass removals included the pine crown and standing hardwood components. These were compared to the observed biomass chip harvests combined with the down material after harvest.

Table 4. Predicted and observed biomass removals (tons/acre) for the four stands where operations are complete, May 2010.

	Predicted Removals				Observed Removals			
County	Pine Bole	Pine Crown	Hdwd	Total	Pine Bole	Biomass Chips	Down Material	Total
Wayne	33.2	6.0	0.3	39.6	32.0	2.5	2.0	36.5
Brantley	44.2	8.6	1.2	54.0	64.0	3.5	2.9	70.5
Randolph	11.8	2.4	28.8	43.0	0	70.9	2.4	73.2
Randolph	8.4	1.7	10.6	20.8	6.8	26.1	1.6	34.5

The tract in Wayne County had predicted and observed pine bole amounts that were within 4 percent of each other. There was potentially 6.3 tons per acre of biomass (pine crown + hardwood) but we observed only 2.5 tons per acre of biomass chips produced with another 2.0 tons per acre of material downed during harvest. In Brantley County, the pine bole prediction of 44.2 tons per acre was exceeded by 19.8 tons per acre during harvest for an overharvest of 45 percent. The biomass estimate of 9.8 tons per acre (pine crown + hardwood) compared to 3.5 tons per acre of biomass chips produced and another 2.9 tons per acre of material downed.

The Randolph County tract that was clearcut produced 70.9 tons per acre of biomass chips and left 2.4 tons per acre on the ground. This compared to a total preharvest estimate of 43.0 tons per acre of biomass (all forms) for an overcut of 27.9 tons per acre or 65 percent. The thinned site in Randolph County produced 6.8 tons per acre of pine bole material compared to 8.4 tons per acre predicted, a shortfall of 1.6 tons per acre or 19 percent. The preharvest biomass estimate of 12.3 tons per acre (pine crown + hardwood) was about half of the biomass chips produced (26.1 tons per acre) with another 1.6 tons per acre left down after harvest. As mentioned earlier both of these tracts had a much larger hardwood component than the other sites in the study. Inventorying stands with large hardwood components can be difficult due to the high number of stems present in each plot. This added difficulty (which was not present at the Wayne and Brantley County sites) likely introduced additional error into our pre and post-harvest inventories. Significant chipping overruns in hardwood stands have been observed for years.

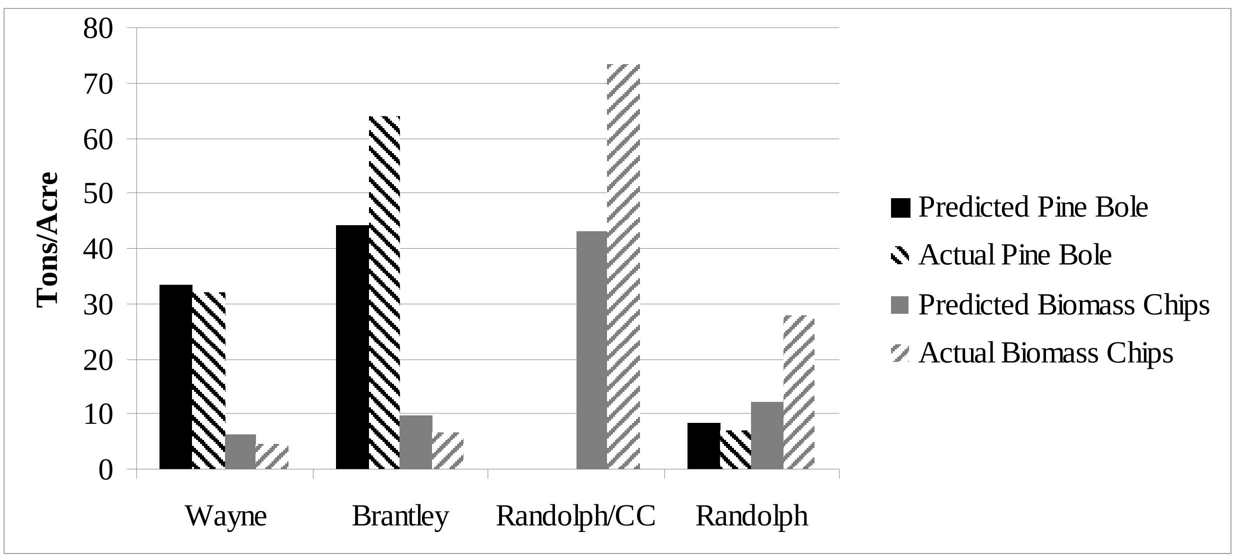

Figure 1. Predicted and actual removals of pine bole and biomass chip materials on four completed harvest tracts in Georgia, 2010.

The ratio of harvested roundwood to harvested biomass chips is a useful comparison because it gives a quick measure of how many tons of roundwood harvest was needed to generate a ton of biomass chips. In Wayne County this ratio was 12.6 and in Brantley County it was 18.1. These ratios are in line with estimates commonly heard in the industry today for commercially recoverable biomass percentages based on roundwood volumes.

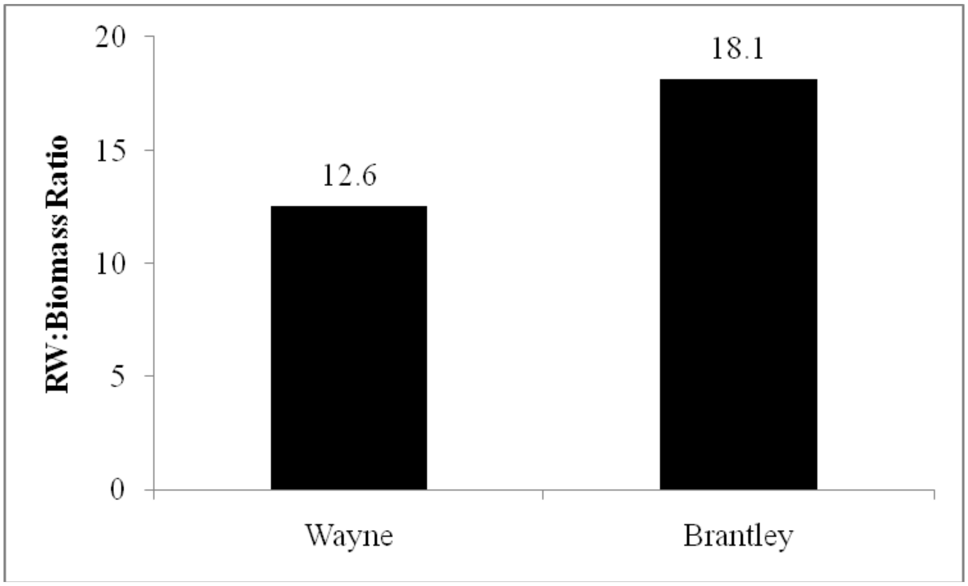

Figure 2. Ratio of harvested tons per acre of roundwood to biomass chips for the Wayne County and Brantley County tracts.

CONCLUSIONS

Using sets of equations that predict residual biomass appear to work more favorably in stands that have high proportions of pine. In this case the stands located in Wayne and Brantley Counties were dominated by their respective crop species and had very little hardwood competition. In both of these stands our estimates of biomass chip removals were slightly higher than the amounts actually harvested. In stands that had large hardwood components, our inventories significantly underestimated biomass chip removals. Accurately measuring hardwood stems in these stands was very difficult because of the sheer quantity of them. Therefore it is not surprising that our inventories underestimated the weight of these stems. Also, the use of a general whole tree weight equation for southeastern hardwoods may have introduced some error into the hardwood weight estimates.

The roundwood to biomass ratios appeared normal for the Wayne and Brantley County tracts, which had significant proportions of pine. These stands were harvested conventionally with the biomass chips as a byproduct of the harvest. The thinned stand in Randolph County had a much lower ratio because a large proportion of the tract was chipped. Fewer loads of pine pulpwood and pine chip-n-saw were cut from the tract because the stand conditions were poor. Therefore more of the harvested material was fed into the chipper and hauled as biomass chips.

ACKNOWLEDGEMENTS

We thank the Georgia Traditional Industries Program for their funding and Plum Creek Timber Company for providing field sites and technical support for this project.

LITERATURE CITED

Avery, T.E. and H.E. Burkhart. 1994. Forest measurements. New York, McGraw-Hill. 408 p.

Baldwin, V.C., Jr. 1987. Green and dry-weight equations for above-ground components of planted loblolly pine trees in the West Gulf region. South. J. Appl. For. 11: 212-218.

Borders, B.E. and B.D. Shiver. 1996. Sampling techniques for forest resource inventory. New York, Wiley. 356 p.

Clark, A.C., J.R. Saucier, and W.H. McNab. 1986. Total-tree weight, stem weight, and volume tables for hardwood species in the Southeast. Ga. For. Res. Pap. 60, Georgia Forestry Commission, Macon. 44 p.

Clark, A.C. and J.R. Saucier. 1990. Tables for estimating total-tree weights, stem weights, and volumes of planted and natural southern pines in the Southeast. Ga. For. Res. Pap. 79, Georgia Forestry Commission, Macon. 23 p.

Harrison, W.M. and B.E. Borders. 1996. Yield prediction and growth projection for site-prepared loblolly pine plantations in the Carolinas, Georgia, Alabama and Florida. PMRC Tech Rep. 1996. Plantation Manage. Coop., D.B. Warnell School of For. Resour., Univ. of Georgia, Athens, GA.

Van Wagner, C.E. 1968. The line intersect method in forest fuel sampling. For. Sci.14: 20-26.

Warren, W.G. and P.F. Olsen. 1964. A line intersect technique for assessing logging waste. For. Sci. 10: 267-276.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Title: Evaluating the use of mobile pyrolysis for the in-woods production of bio-oil and biochar from forest treatment residues: A comparison of three alternative technologies.

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Abstract:

Recent research has highlighted the potential use of mobile pyrolysis reactors to produce biochar and bio-oil from forest treatment residues close to the harvest site. In theory, this technology reduces the need to transport bulky, low-value biomass long distances to a centralized facility and can provide revenues to help offset some of the costs of forest treatment operations. In addition, using advanced pyrolysis technologies for residue disposal is less polluting than on-site open burning, which is currently the only financially viable disposal option in many areas of the Interior West. As with many new technologies, significant gaps remain in our understanding of how mobile pyrolysis performs under field conditions and how it might be integrated into existing operations and management activities. Researchers from the University of Montana and the USDA Forest Service Rocky Mountain Research Station have been working closely with a wide range of industry partners to understand the productivity and financial feasibility of these systems and to characterize the chemical and physical properties of the emissions, synthesis gas, biochar and bio-oil they produce. The authors present a preliminary analysis based on data collected from three prototype pyrolysis reactors manufactured by different companies using different technologies. They also provide an assessment of the benefits and challenges associated with up-scaling and deploying mobile pyrolysis technology for commercial applications, with an emphasis on the use of these systems as a component of fuel reduction, salvage and sanitation treatments in the Interior West. Though mobile pyrolysis is in the early stages of development in the forest sector, results indicate that it has the potential to reduce emissions and offset costs under certain production and market conditions.

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Title: A productivity and cost comparison of hog fuel production using slash forwarding and in-woods grinding of cured harvest residues.

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Abstract: Forest operations generate large quantities of woody biomass in the form of residues from timber harvests, pre-commercial thinning, and fuel reduction projects. Often, this material is concentrated on forest landings and along roads that are inaccessible to large chip vans and distant from facilities that use biomass as fuel or raw material. In many regions, open burning represents the only financially viable option for disposal of forest residues. In order for this biomass to be used for bioenergy production, efficient methods of handling, processing and transporting these materials must be developed. We present a comparison of two alternative operational configurations to produce hog fuel from harvest residues that are inaccessible to chip vans: (1) forwarding slash in fifth-wheel dump trailers to a centralized concentration yard where it can be stored and then ground directly into large chip vans, and (2) grinding slash at the harvest site and forwarding the hog fuel in high-sided dump trucks to a concentration yard where it can be stored and re-loaded into large chip vans. To quantify the productivity and costs of these systems, time study data were collected for both configurations on the same harvest unit in northern Idaho in July, 2009. The combined operations moved over 1400 bone dry tons (bdt) of biomass over the course of the study. The observed average productivities of the handling and hauling operations of the slash forwarding and in-woods grinding operations were 18.8 bdt per scheduled machine hour (SMH) and 23.1 bdt per SMH, respectively. Operations at the concentration yard averaged 41.3 bdt per SMH for grinding and loading concentrated slash and 62.9 bdt per SMH for loading piled hog fuel. Using standard machine rate calculations, the observed costs from slash pile to loaded chip van were $24.8 per bdt for slash forwarding and $24.5 per bdt for in-woods grinding. However, sensitivity analyses show that the productivity and costs of these operations are sensitive to haul distance, slash configuration, grinder mobilization time, system balance, and other variables, with slash forwarding most appropriate for sites with dispersed residues and long-distance in-woods grinder mobilization.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Discussion on economy and energy balances of forest residues for Bio-energy at Sano city, Tochigi prefecture in Japan

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ABSTRACT

To discuss the harvesting system considering extracting forest residues for supplying to a biomass power plant, we estimated harvesting volumes and costs using GIS at Sano city, Tochigi prefecture in Japan. Forest-registration data (stand ages, tree species, and site indexes) and GIS data (information on roads and subcompartment layers) from the Tochigi Prefectural Government were used in the study, as were 50 m-grid digital elevation models (DEM) from the Geographical Survey Institute. As a result, the minimum and average costs of Cut-To-Length system with forwarders were 4,424 yen/m^3 and 8,206 yen/m^3, respectively. Only 0.08% of subcompartments were extracted as those costs below 4,500 yen/m^3.

Energy input increases as harvesting volumes of forest residues increases. However, the maximum energy input, 0.08 GJ/m^3 was still lower than potential energy of wood, 4.06 GJ/m^3. Same with energy input, CO_2 emission increases as harvesting volumes of forest

residues increases. However, the maximum CO_2 emission, 6 $kgCO_2/m^3$ was still lower than sequestered CO_2 in wood, 576 $kgCO_2/m^3$. Therefore, this system would be energy-effective.

In order to reduce costs, subsidy and whole tree logging system were considered. As a result, the average costs with subsidy were reduced to 5,719 yen/m^3 and 41% of subcompartments were extracted. The average costs of stem extraction without branches were also reduced to 7,995 yen/m^3. The minimum and average costs of whole tree logging system were significantly reduced to 1,182 yen/m^3 and 5,911 yen/m^3, respectively. Moreover, costs considering timbers extraction were also reduced. Therefore, the whole tree logging system could be more advantageous for extracting forest residues than the Cut-To-Length system.

($1=92.76 yen on March 28, 2010)

Key Words: forest residues, harvesting systems, GIS, Subsidy, Whole tree logging

INTRODUCTION

Forest has important roles in realizing the low-carbon society in that forest sequesters carbon from the atmosphere and produces wood: one of typical renewable resource which stores sequestered carbon. Therefore, forest needs to be continuously and properly managed and the use of wood, particularly domestic one, should be promoted. Forestry in Japan, which is necessary for forest management as well as wood production, faces many difficulties; shrinking domestic wood demand, declining wood prices and deteriorating profitability. If the situation remains unchanged, the population in mountainous areas is expected to decrease and become older, resulting in lack of proper forest management (Japan Forestry Agency 2009).

Revenues increase from the sales of value-added wood products or the Domestic Credits and the Offsetting Credits (J-VER), as well as cost reduction at each stage from wood production to processing, might improve the profitability of forestry, revitalizing forestry industry and communities in mountainous areas. Proper care of forests in mountainous areas and effective wood use while revitalizing forestry industry and communities in mountainous areas are the keys to the realization of the low-carbon society (Japan Forestry Agency 2009).

Woody biomass can be categorized into forest residues, sawmill residues and construction waste woods. Although the introduction of wood-fired boilers and generators and the production of wood pellet have been steadily increasing in recent years, large amount of woody biomass, in particular forest residues, still remains unused (Figure 1). In order to utilize forest residues as energy in a region where forestry is the major source of income, it is crucial to find out the relationship between the available amount and the procurement (harvesting and transporting) cost of forest residues in the region.

In this study, feasibility of the energy utilization of forest residues in a mountainous region in Japan is discussed with the aid of the GIS. To discuss the harvesting system considering extracting forest residues for supplying to a biomass power plant, we estimated harvesting volumes and costs using GIS at Sano city, Tochigi prefecture in Japan. Forest-registration data (stand ages, tree species, and site indexes) and GIS data (information on roads and subcompartment layers) from the Tochigi Prefectural Government were used in the study, as were 50 m-grid digital elevation models (DEM) from the Geographical Survey Institute. Then, in order to reduce costs, subsidy and whole tree logging system were considered. Finally, the energy balance and the carbon dioxide (CO_2) emission were analyzed using the method of a life cycle inventory.

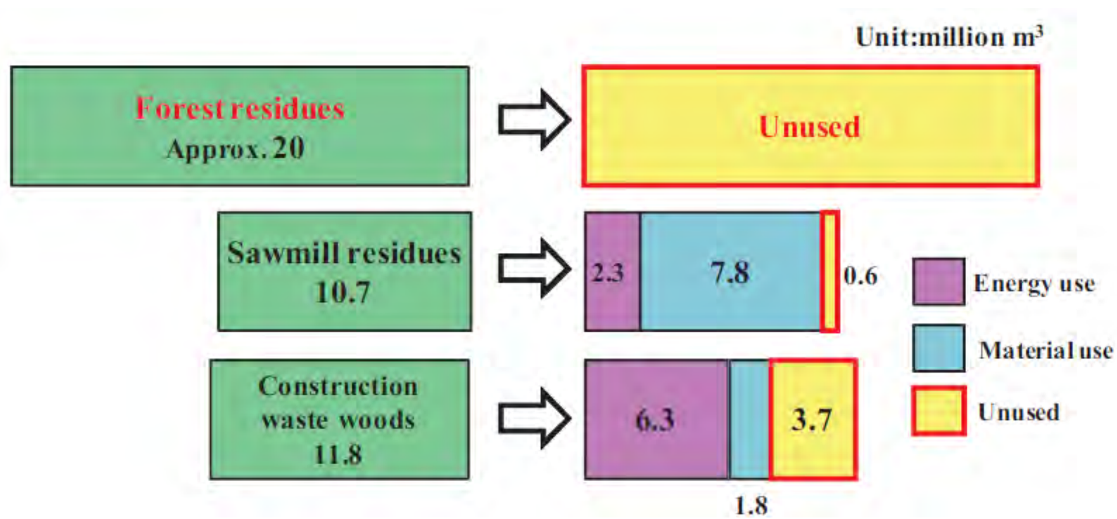

Figure 1 Sources and Utilization of Woody Biomass (Japan Forestry Agency 2009)

STUDY SITE AND DATA

Study site is Sano City in Tochigi Prefecture, Japan (Figure 2). The gross area is 35,607 ha, the forest area is 21,839 ha (the percentage to the gross area is 61%). Most of the tree species are conifers; Japanese cedar and Hinoki cypress account for 39% and 23% of the trees, respectively (Figure 3). Most of conifers are within 45-50 years old (Figure 4). According to site-index which indicates the order of the production capacity of the stands by three classes and the smaller number is, the larger production capacity is. Site-index 1 is 72%, Site-index 2 is 23%, and Site-index 3 is 5% (Figure 5). Most of forests are relatively steep and average inclination is 32 degrees (Figure 7). The density of the road network is relatively high, 53 m/ha.

Forest-registration data (stand ages, tree species, and site indexes) and GIS data (information on roads and subcompartment layers) from the Tochigi Prefectural Government were used in the study, as were 50 m-grid digital elevation models (DEM) from the Geographical Survey Institute. Using these materials and the GIS, the available amount of forest residues was estimated and the distribution map was made based on sub-compartments which were usual operational units in Japan.

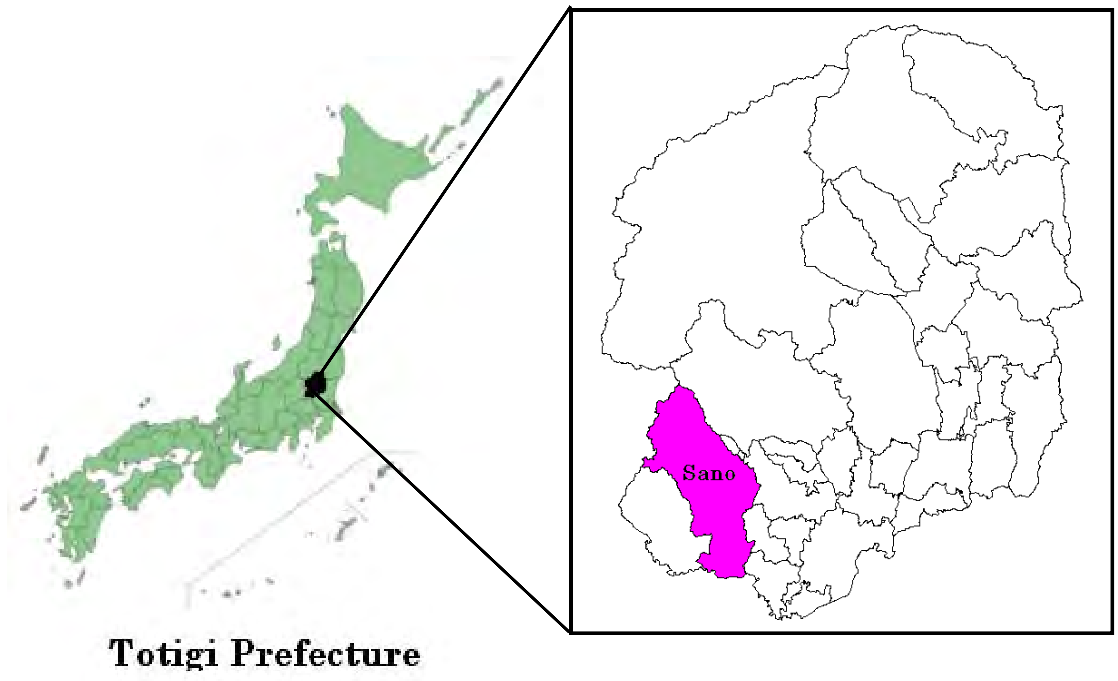

Figure 2 Study site

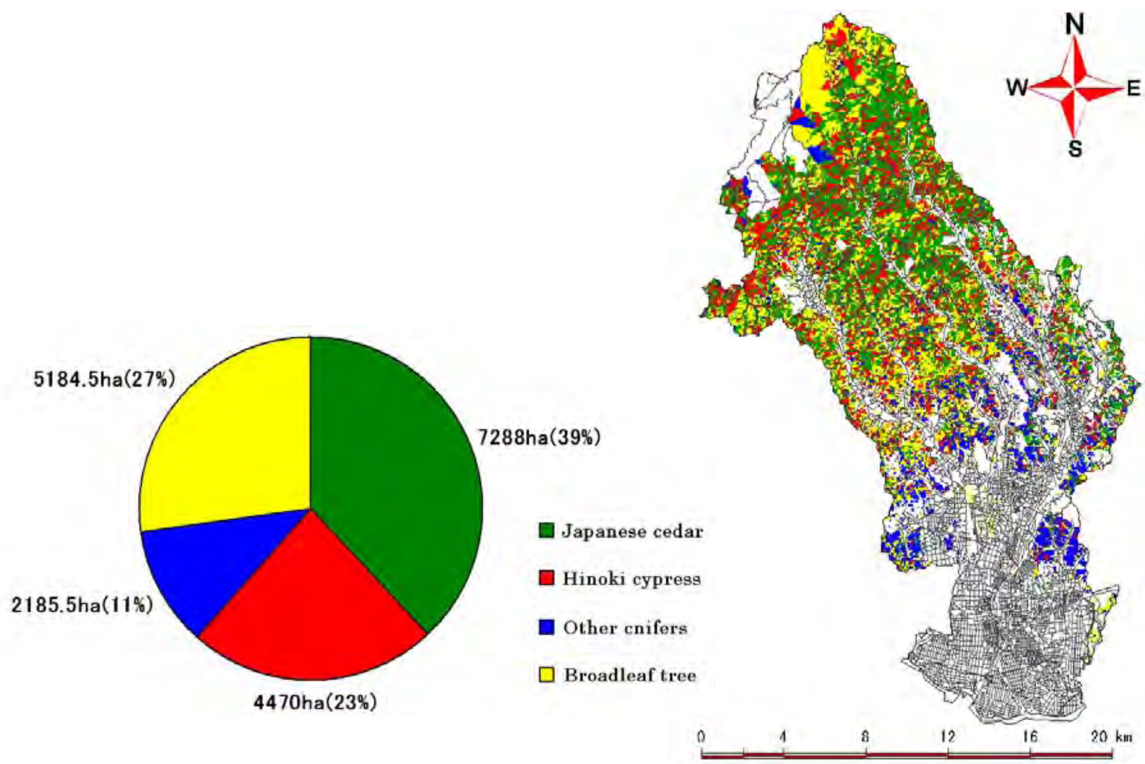

Figure 3 Stand species

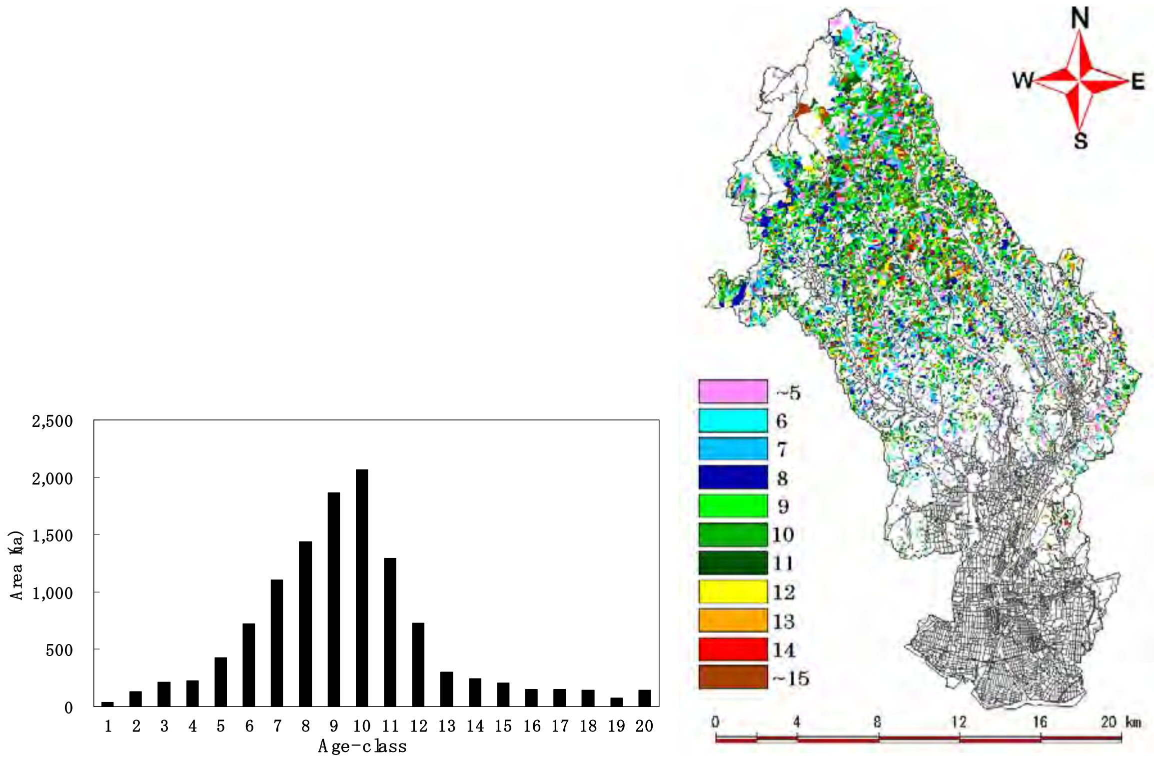

Figure 4 Stand age class (5 years each class)

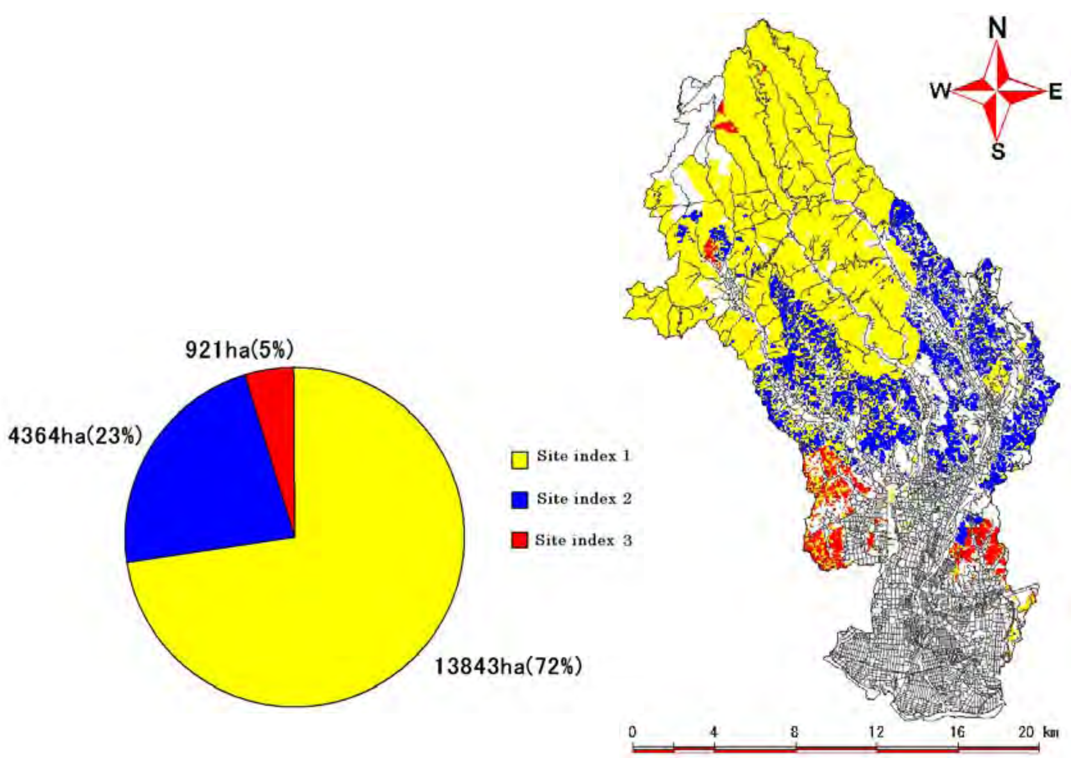

Figure 5 Site index

METHODS

Procurement costs

Harvesting and transporting systems were shown in Figure 6. Table 1 lists the operation patterns of sub-compartments to be felled. Logging residues are considered as a by-product of conventional forestry. Therefore, the system boundary of logging residues starts with forwarding by forwarders (Figure 6). Table 2 shows the machine specification and Table 3 shows the equations for calculating the harvesting and transporting costs of logging residues whose variables are logging distance L_Y (m), slope θ (degree), harvesting volumes per ha V (m^3/ha), area A (ha), and transporting distance L_T (m). Payloads are changed according to forwarding and transporting parts such as stems and branches (Table 4). Therefore, forwarding and transporting expenses are classified into three equations (Table 3).

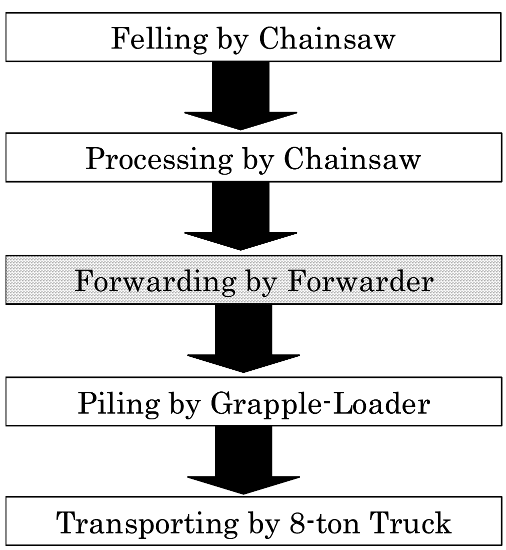

Figure 6 Harvesting system (Cut-To-Length system)

Table 1 Harvesting condition

	First (pre-commercial) thinning	Second (commercial) thinning	Clear cutting
Age	25～39	40～59	60～
Cutting rate	25%	35%	100%
Extracting rate	80%	111%*	111%*
Logging residues rate	100%	55%	26%
Timber rate	0%	45%	74%

* including branches

Table 2 Parameters for machine expenses

		Machine prices (thousand Yen)	Duration (Years)	Annual operation time (h/year)	Depreciation rate	Maintenance and repair rate	Annual administration rate	Fuel consumption(ℓ/h)	Productivity (m^3/h)
Chainsaw	Felling	202	3	900	0.9	0.85	0.065	2.8	3.0
Chainsaw	Processing	202	3	900	0.9	0.85	0.065	2.8	7.5
Forwarder	Part 1	6,250	5	1,080	0.9	0.96	0.065	1.4	10,191/*Ly*
	Part 2								5,254/*Ly*
	Part 3								15,168/*Ly*
Grapple-Loader		9,500	6	1,200	0.9	0.31	0.049	3.9	15.0
8-Ton Truck	Part 1	10,180	5	1,100	0.9	0.40	0.100	8.2	166,500/*Lt*
	Part 2								85,500/*Lt*
	Part 3								247,423/*Lt*
Tractor		9,600	6	1,080	0.9	1.08	0.065	4.3	5,440/*Ly*
Tower-Yarder	Small	6,880	6	900	0.9	0.96	0.065	1.5	1,080/(2*Ly*+80)
Tower-Yarder	Medium	36,000	6	900	0.9	0.96	0.065	3.0	4,860/(2*Ly*+243)
Yarder		5,890	7	900	0.9	0.96	0.065	2.8	$12.067Ly^{-0.2142}$

Ly : Logging Distance (m), *Lt* : Transporting Distance （m）

Part 1) Logging residues from First thinning, Part 2) Logging residues from Second thinning and Clear cutting, Part 3) Timbers

Fuel unit expenses are assumed to be 80 yen/ℓ. Oil expenses are assumed to be 20% of Fuel expenses.

Table 3 Operation expenses

Machine	Operation	Part	Expenses(Yen/m^3)
Chainsaw	Felling and Processing		1,212
Forwarder	Forwarding	1	$0.435Ly+2,845\underline{+27,510e^{0.117\theta}/V}$
		2	$0.845Ly+2,845\underline{+27,510e^{0.117\theta}/V}$
		3	$0.292Ly+2,845\underline{+27,510e^{0.117\theta}/V}$
Grapple-Loader	Piling		270
8-Ton Truck	Transporting	1	$0.039Lt+778$
		2	$0.076Lt+778$
		3	$0.026Lt+778$
Tractor	Skidding		$1.031Ly+1,669\underline{+27,510\ e^{0.117\theta}/V}$
Tower-Yarder(Small)	Yarding		$14.925Ly+617\underline{+4,207,500/LyV}$
Tower-Yarder(Medium)	Yarding		$8.369Ly+1,108\underline{+3,786,750/LyV}$
Yarder	Yarding		$759.532Ly^{0.2142}+196+\underline{3,271,752/LyV+104,009/V}$
Landing-establishment expenses			$165.224+7,211/VA$

Ly : Logging Distance (m), θ : Inclinations of Operation sites (degree),
V : Harvest Volumes (m^3/ha), A : Area (ha), Lt : Transportation Distance （m）
Part 1) Logging residues from First thinning, Part 2) Logging residues from Second thinning and Clear cutting, Part 3) Timbers,
Underlines indicate logging trail establishment expenses, and Yarding set up expenses, respectively.

Table 4 Payloads (m^3)

Part	1	2	3
Extracting part	Stems	Stems and Branches	Stems
Logging	2.58	1.33	3.84
Transportation	11.1	5.7	16.49

Part 1) Logging residues from First thinning, Part 2) Logging residues from Second thinning and Clear cutting, Part 3) Timbers

The following items on topography were processed on the GIS software. The average angle of inclination of each sub-compartment was estimated (Figure 7). Logging distances were estimated as average distances from landings to all grids within sub-compartments (Figure 8). Landings were set within grids in such a manner as to minimize distances from roads, centers of gravity in sub-compartments, and log market. The log market managed by a Forestry Cooperative was selected in the analysis. As simply method, transportation distance was supposed to be calculated with a straight line distance from landing in each sub-compartment to chip factory or log market using detour ratio (Figure 9). Detour ratio is different from the physiographic division (Kobayashi 1997). The terrain of the study site is relatively steep. Therefore, detour ratio was set to 0.4. By applying the topographical data on each sub-compartment to the equations listed in Table 3, procurement costs from all sub-compartments in the region can be estimated.

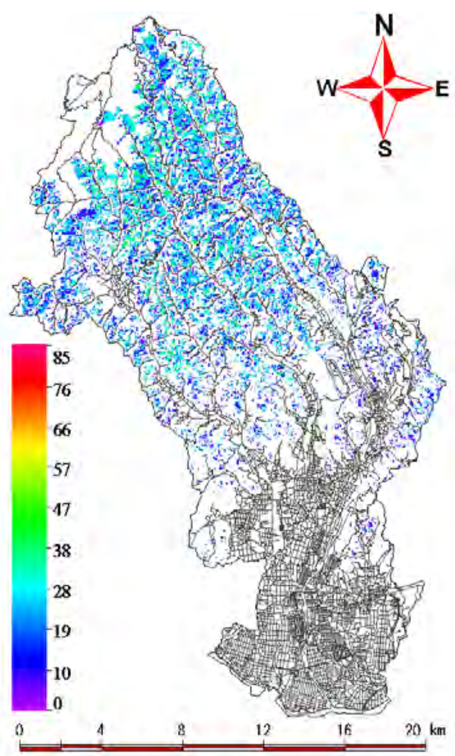

Figure 7 inclination (degrees)

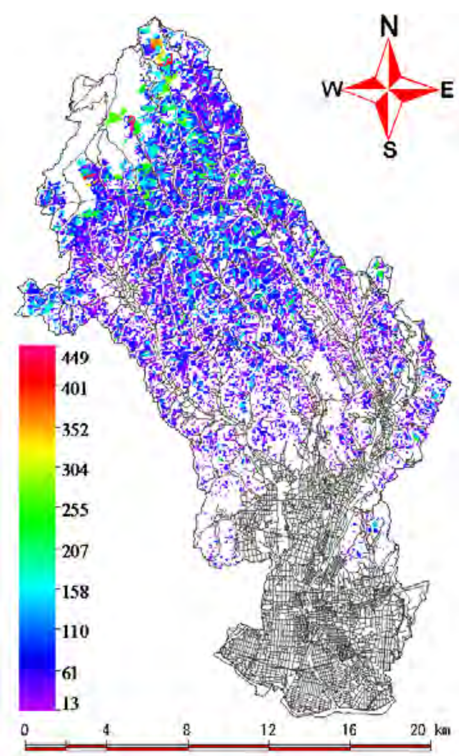

Figure 8 logging distance (m)

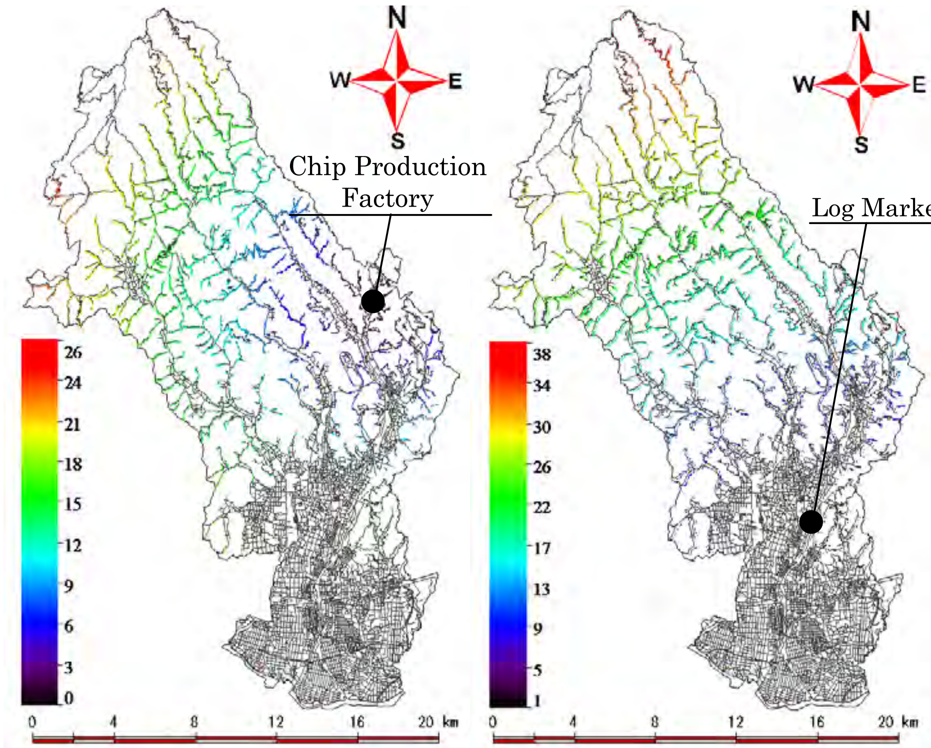

Figure 9 Transporting distance (km) to chip factory (left) and to log market (right)

Volumes

The volume for each sub-compartment was estimated using yield tables (Table 5, Forestry examination plantation of The Forestry Agency, 1955 and 1962) with stand species, ages, and site indexes in the present forest registration (Figure 10). We set out to study only Japanese cedar and Hinoki cypress, which are major species in Japanese plantation forests.

Table 5 Yield Table

Age	Volume (m^3/Ha)					
	Cedar	Hinoki	Cedar	Hinoki	Cedar	Hinoki
	Site Index 1		Site Index 2		Site Index 3	
10	54.5	40.2	34.0	30.3	20.5	23.2
15	149.9	92.3	99.6	64.6	61.3	44.2
20	244.9	140.4	169.6	101.4	109.5	67.4
25	329.5	184.8	234.4	135.6	155.2	92.5
30	403.5	225.1	291.2	166.8	197.2	116.7
35	471.5	260.0	344.3	194.6	236.2	138.8
40	534.5	290.7	394.0	219.4	272.6	158.6
45	593.6	318.3	439.5	241.4	306.8	175.8
50	649.8	342.7	483.0	261.1	339.0	190.2
55	702.1	364.8	523.6	278.4	369.3	201.8
60	751.3	384.4	561.6	294.0	397.9	210.0
65	797.5		597.2		424.9	
70	841.0		630.5		450.5	
75	881.9		662.0		474.9	
80	920.8		691.8		498.2	
85	958.0		720.8		520.6	
90	993.4		748.8		542.2	
95	1027.3		776.0		563.2	
100	1059.9		802.5		583.6	

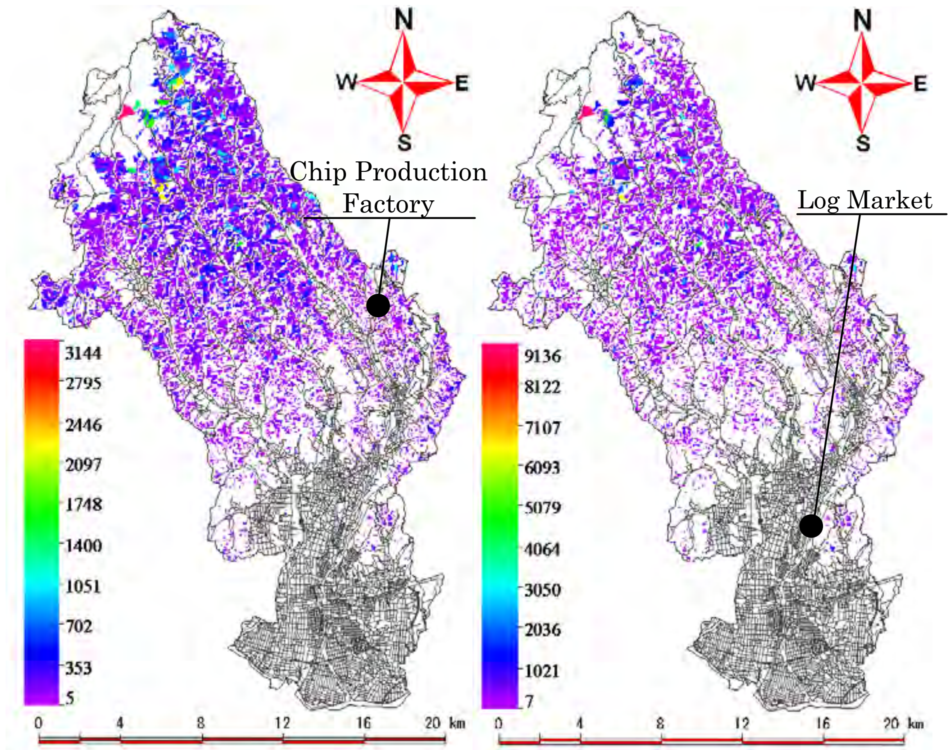

Figure 10 harvesting logging residues (left) and timber (right) potential on each sub-compartment (m^3)

Energy balance

Only operation energy was considered as the energy input into the system in this study although the energy input into the system should consist of the equipment and operation energies over the entire life cycle of the plant (Yoshioka et al 2005). Operation energy was defined as the energy necessary for operating a system and is composed of the fuel consumption of forestry machines.

The quantity of required fuel is calculated from the fuel consumption of each machine, the productivity of each machine, and harvesting volumes of logging residues (Table 2). The gasoline is used for fuel of chainsaw and light oil is used for fuel of other machines. Energy densities of gasoline and light oil are 34.6 MJ/L and 38.2 MJ/L, respectively (Ministry of the Environment 2005).

In addition, the CO_2 emissions from all the processes of the system were examined. The CO_2 emissions are estimated from energy input into each process and the CO_2 emission per unit energy of each energy resource. The CO_2 emissions from gasoline and light oil per unit energy are 67.10 $kgCO_2$/GJ and 68.70 $kgCO_2$/GJ, respectively (Ministry of the Environment 2005).

RESULTS

Economic balance

The minimum and average costs of Cut-To-Length system with forwarders were 4,424 yen/m^3 and 8,206 yen/m^3, respectively (Figure 11). Only 0.08% of subcompartments around the chip factory were extracted as those costs below 4,500 yen/m^3 which was the target price of the chip factory (Figure 12).

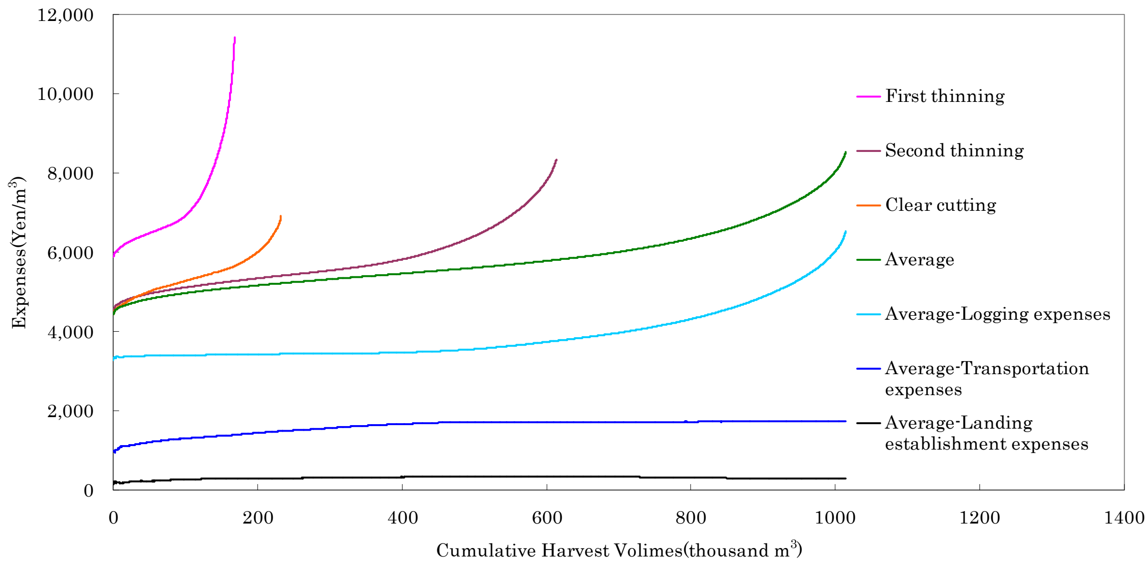

Figure 11 Direct costs of extracting logging residues

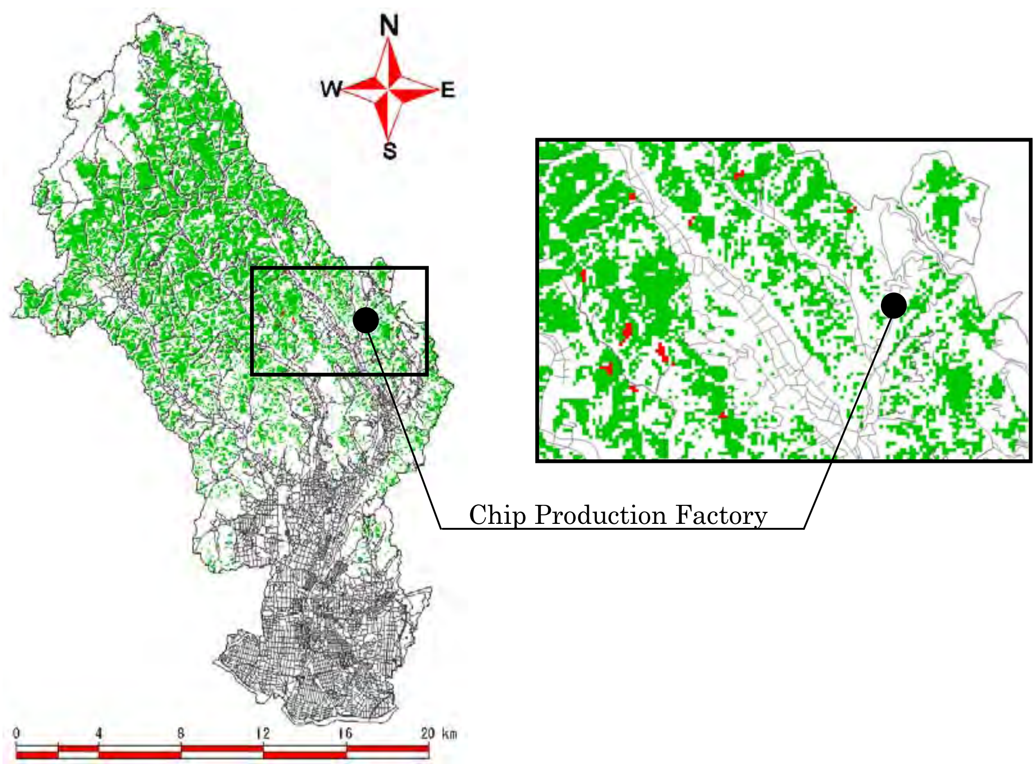

Figure 12 Extracted sub-compartments (Red) and the closeup around the factory

Energy balance

Energy input increases as harvesting volumes of logging residues increases (Figure 13). However, the maximum energy input, 0.08 GJ/m^3 was still lower than potential energy of wood, 4.06 GJ/m^3. Same with energy input, CO_2 emission increases as harvesting volumes of logging residues increases (Figure 14). However, the maximum CO_2 emission, 6 kgCO_2/m^3 was still lower than sequestered CO_2 in wood, 576 kgCO_2/m^3. Therefore, this system would be energy-effective.

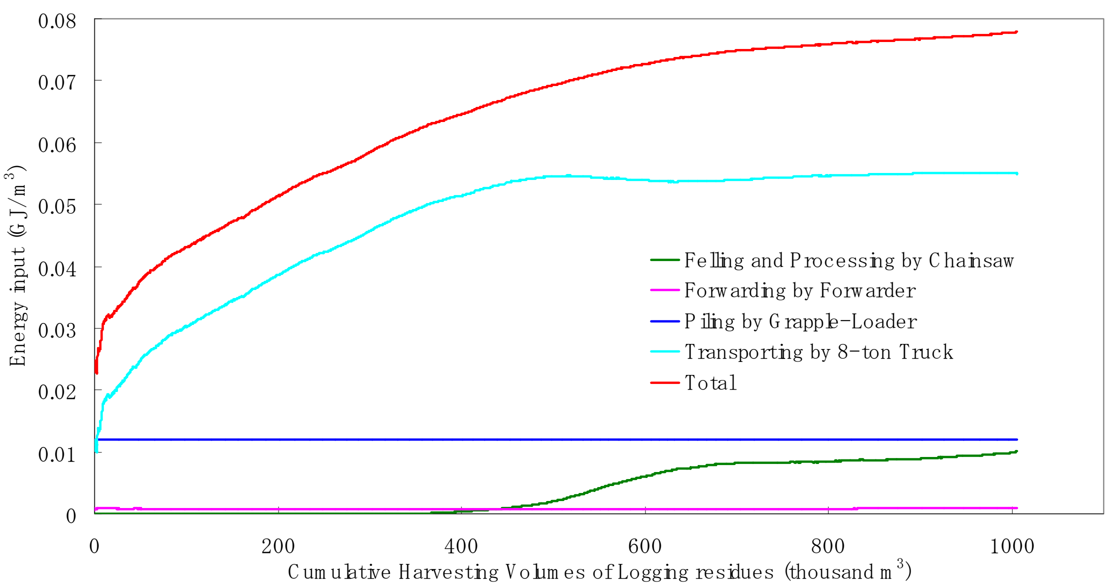

Figure 13 Energy input

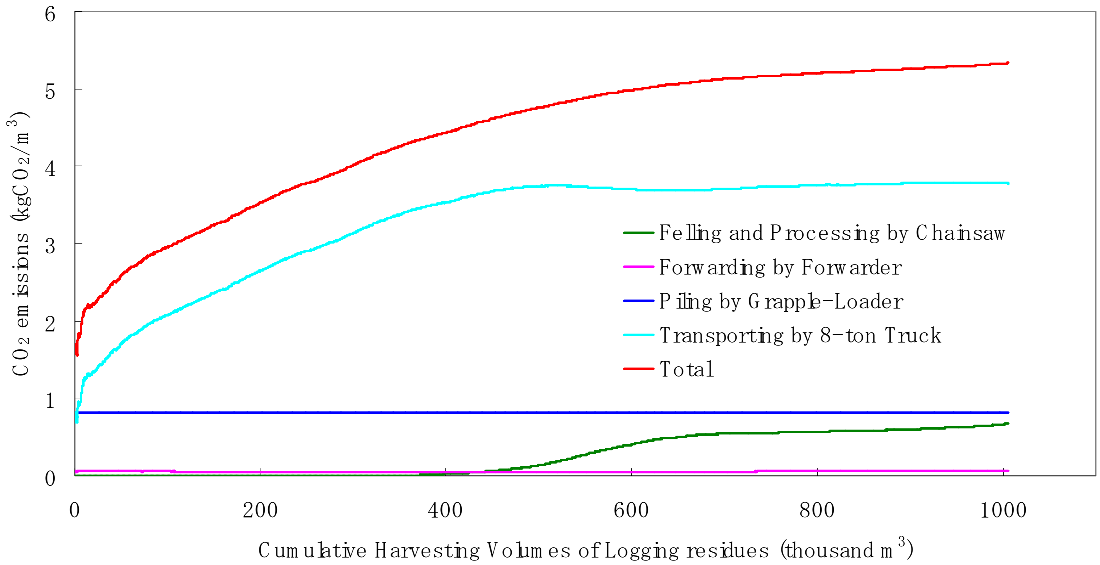

Figure 14 CO_2 emissions

DISCUSSIONS

In order to reduce costs, subsidy and whole tree logging system were considered. Subsidies were assumed 201,872 yen/ha for 25 year-old forests and 198,912 yen/ha for 26-35 year-old forests at the first thinning. In addition, logging trail establishment expenses were assumed to be covered by subsidies at the second thinning and the clear cut. As a result, the average costs with subsidies were reduced to 5,719yen/m^3, and 41% of subcompartments were extracted (Figure 15).

As for the whole tree logging system, tractors (skidders), tower yarders (mobile yarders), and yarders were assumed to be used for the skidding/yarding process (Figure 16 - 18). Since the system boundary of logging residues starts with piling by grapple-loader (Figure 16), the minimum and average costs of whole tree logging system were significantly reduced to 1,182yen/m^3 and 5,911yen/m^3, respectively (Figure 19). Moreover, costs considering timbers extraction were also reduced. Therefore, the whole tree logging system could be more advantageous for extracting logging residues than the Cut-To-Length system.

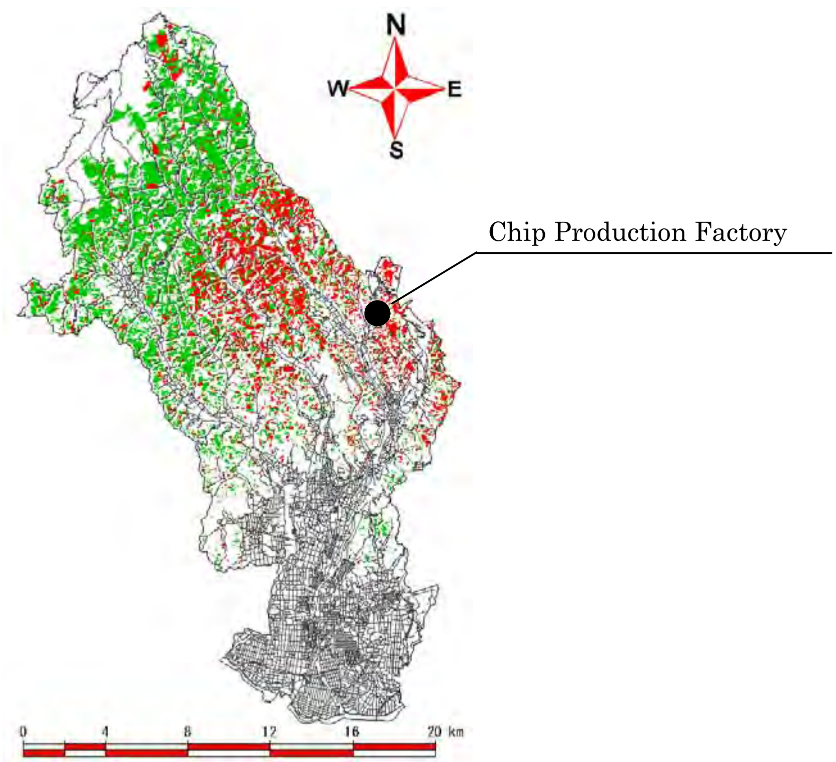

Figure 15 Extracted subcompartments (Red) with Subsidies

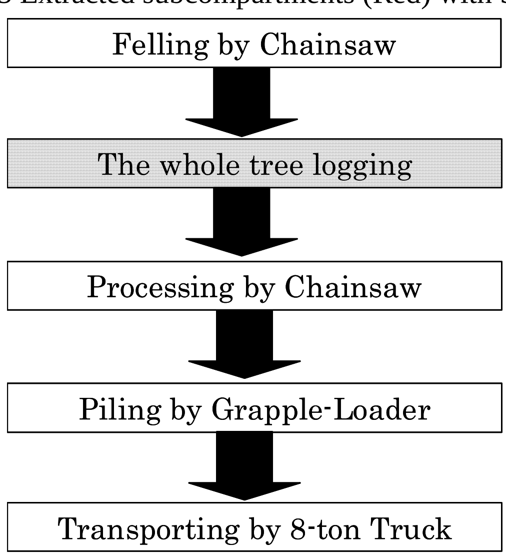

Figure 16 Harvesting system (Whole tree logging system)

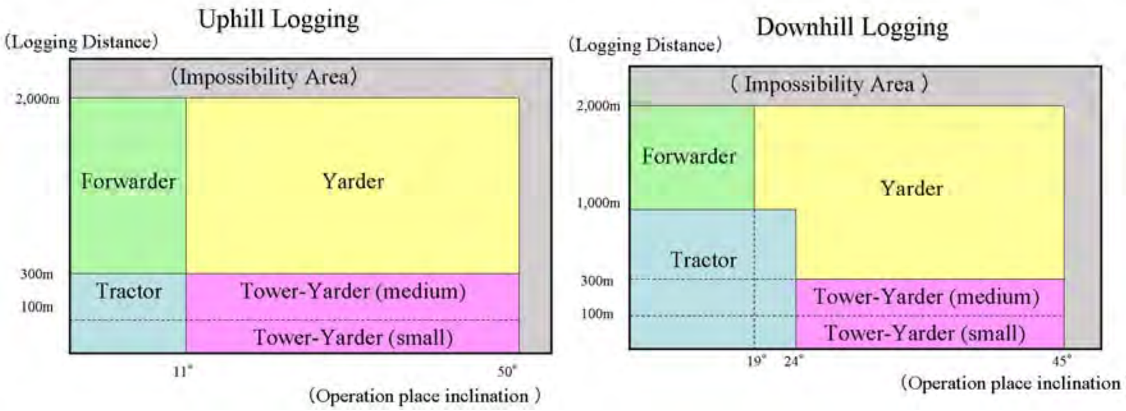

Figure 17 Logging machine selection

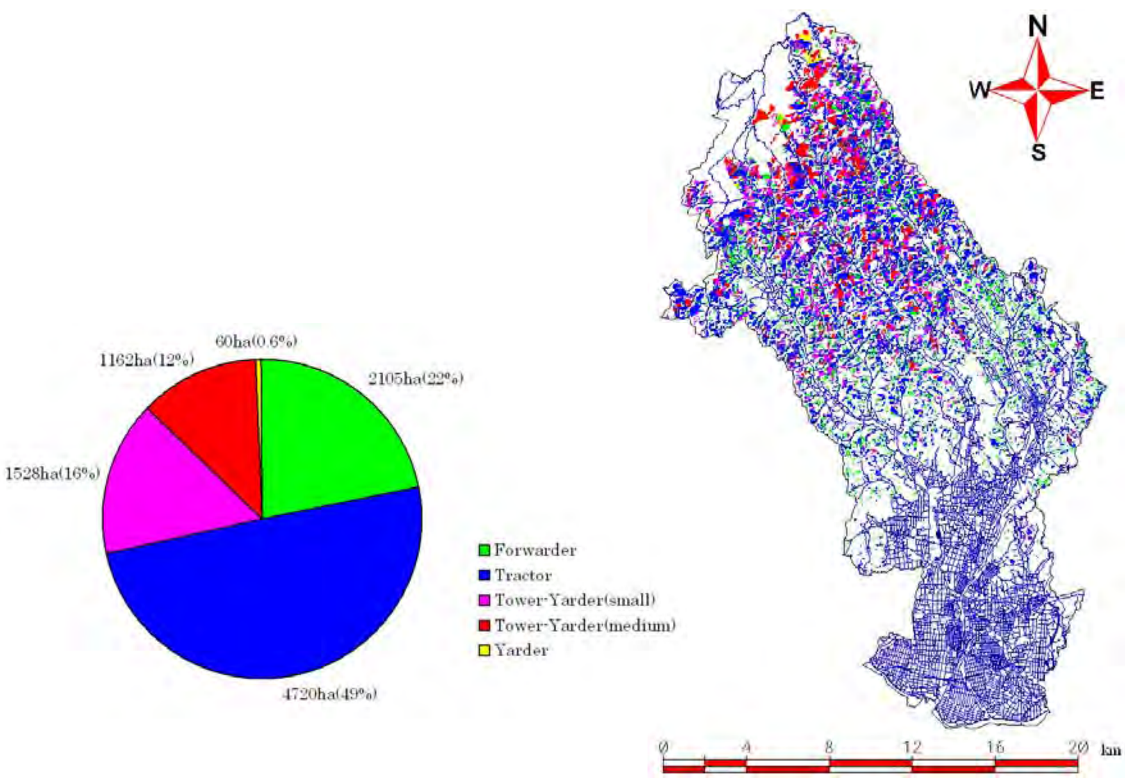

Figure 18 Selected machines

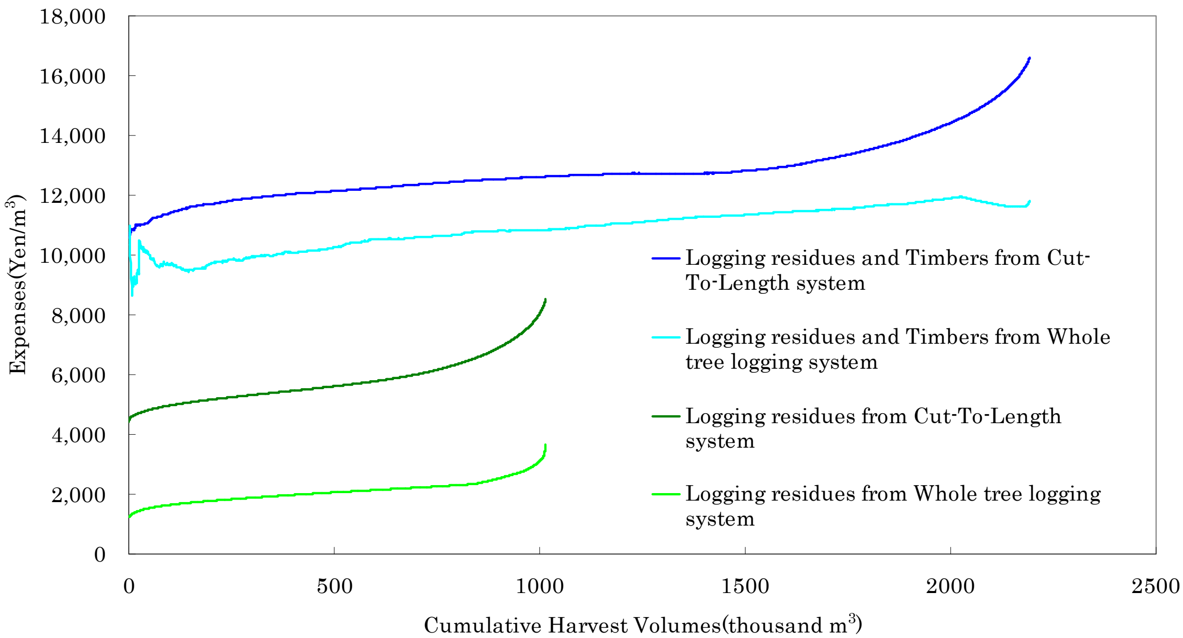

Figure 19 Direct costs of extracting logging residues and timbers

REFERENCES

KOBAYASHI, H., (1997): Forest Infrastructure Plan Theory. Nihon Ringyo Kyokai, Tokyo, 205pp (in Japanese)

Japan Forestry Agency (2009) Annual Report on Trends on Forest and Forestry.

Ministry of the Environment (2005) Guideline for the method to calculate GHG emissions from organizations. 83pp, Ministry of the Environment, Tokyo.

YOSHIOKA, T., ARUGA, K., NITAMI, T., KOBAYASHI, H. and SAKAI, H. (2005) Energy and carbon dioxide (CO_2) balance of logging residues as alternative energy resources: System analysis based on the method of a life cycle inventory (LCI) analysis. Journal of Forest Research 10: 125～134.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Impact of Timber Sale Characteristics on Harvesting Costs

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Abstract

Large changes have taken place in the forest industry in the past decade with record high and low home construction levels, the dissolution of vertically integrated forest products companies, and record high fuel costs. All of these shifts have impacted the timber harvesting workforce. We gathered data on timber sales from across the southeastern United States from 2000 through 2008 to examine what changes had occurred in harvest tract characteristics. Among the trends observed were an increase in average tract acreage and substantial increases in partial harvesting. These data were then used to model harvesting costs in the Auburn Harvesting Analyzer, in an effort to determine what trends existed. Little long-term impact to harvesting costs could be attributed to timber sale characteristics.

Introduction

Across much of the country, forestland ownership patterns have shifted dramatically. Lands previously owned by vertically integrated forest products companies have been divested, typically to land management organizations seeking to provide competitive financial returns to company shareholders. It has been theorized that the management approach of these new landowners will be different. We undertook a project to determine what changes have occurred in the characteristics of harvested tracts since 2000, and ultimately, what impact this may have had on harvesting costs over the same timeframe.

Methods

Individual timber sale data from across the South were compiled from Timber-Mart South for each quarter from January 1, 2000 through December 31, 2008. These data included sale date, acreage, location, total volume, total sale price, and harvest type. The data were processed using SAS to provide a single record for each of the 18,006 individual sales. Many of these did not include data needed for the analysis as most Timber-Mart South reports focused mainly on prices rather than harvest tract information (Harris *et al.* 2009). When only sale records including acreage were retained, the dataset included 9,540 individual timber sales.

Sales records were analyzed by quarter to provide South-wide average harvest characteristics. The data were split for this analysis into clearcuts and partial harvests, with salvage sales removed from the analysis. Four-quarter moving averages were generated to clarify trends in the data. Medians were generated from the data for quarterly measures of central tendency as means were greatly influenced by large outliers in a significant percentage of the quarters examined. Kolmogorov-Smirnoff tests for normality in the data also verified that more robust estimators were needed than simple means.

The Auburn Harvest Analyzer was adapted to accept inputs of quadratic mean diameter, tract acreage, and volume per acre as variables (Tufts *et al.* 1985). A standard feller-buncher, two skidder, one knuckleboom loader system was used to estimate harvesting costs for crews typical in the Southeastern U.S. (Baker and Greene 2008). An array of possible input values were used to examine the sensitivity of the modeled costs to these three input variables. Quarterly median values from Timber-Mart South were input into the model to calculate harvesting cost changes for an average logging system based on the changes in observed tract characteristics.

Exact Kendall's tau and Spearman correlation coefficients were calculated to account for the small sample size associated with the relatively short timeframe of available data (Hollander and Wolfe 1999).

Results

Clearcutting as a percentage of all sales began a steady decline in 2005 while the median sale acreage per year began to increase (Table 1). Median total tons harvested remained relatively stable throughout the period. Abnormally low volumes in 2004 are likely a result of very low reporting of harvest volumes in all four quarters of that year.

Table 1. Summary of timber sale data by year based on Timber-Mart South data for the Southern states.

Year	Number of Sales	Median Acreage	Median Total Tons	Median Tons/Acre	Clearcut (% of all sales)
2000	1096	75	2499	36.3	53
2001	969	78	4150	53.8	58
2002	1054	78	4683	62.1	56
2003	1031	81	5482	54.7	54
2004	1056	78	2900	38.1	57
2005	1480	99	3841	42.2	49
2006	880	92	4604	45.8	46
2007	1112	99	4221	42.9	46
2008	859	102	4500	40.0	43
Total or Mean	9540	85	4234	46.9	52

The proportion of clearcutting and partial cutting has varied over the past nine years in the South (Figure 1). When observing total acres cut, partial harvests have been performed on more acres each quarter for almost the entire period. On average, over the entire dataset, partial harvests have been performed on 59.5% of the reported harvested acreage, compared to 40.5% for clearcutting. This balance has shifted more heavily towards partial harvests in recent years, averaging 68.9% partial harvesting and 31.1% clearcutting in 2008.

The median acreage of tracts harvested during this time period fluctuated from quarter to quarter, but showed minor trends over the entire timeframe (Figure 2). Median tract size trended up slightly, with median clearcut size around 80 acres and median partial harvest size around 120 acres. For a given quarter, median harvest size varied between 100 and 200 acres for partial harvests and between 75 and 115 acres for clearcuts. The median values for harvested acreage varied in a much narrower range (Figure 2).

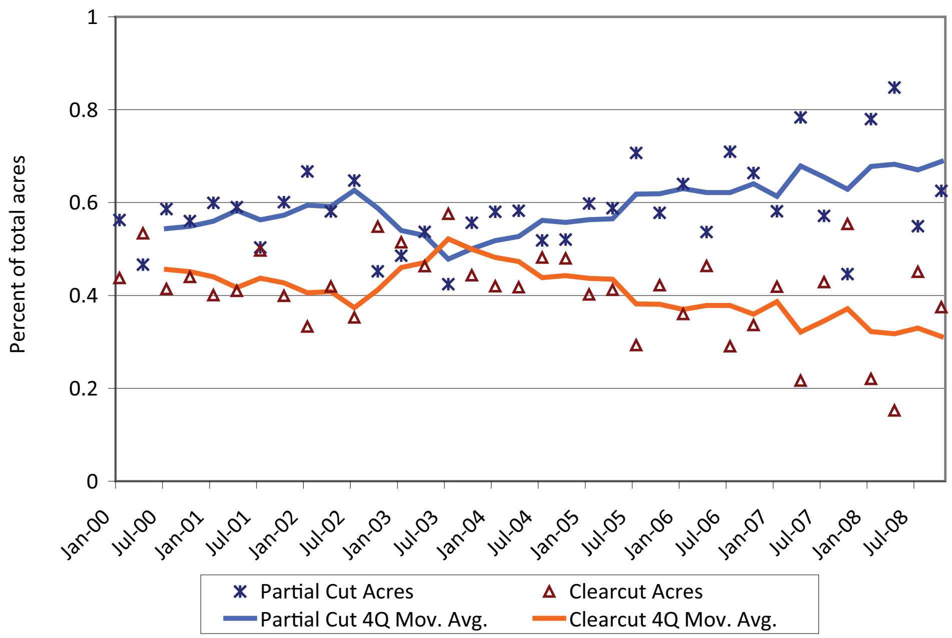

Figure 1. Relative proportion of total acres harvested in clearcut and partial cutting from January 2000 through December 2008. Four quarter moving averages are shown by lines.

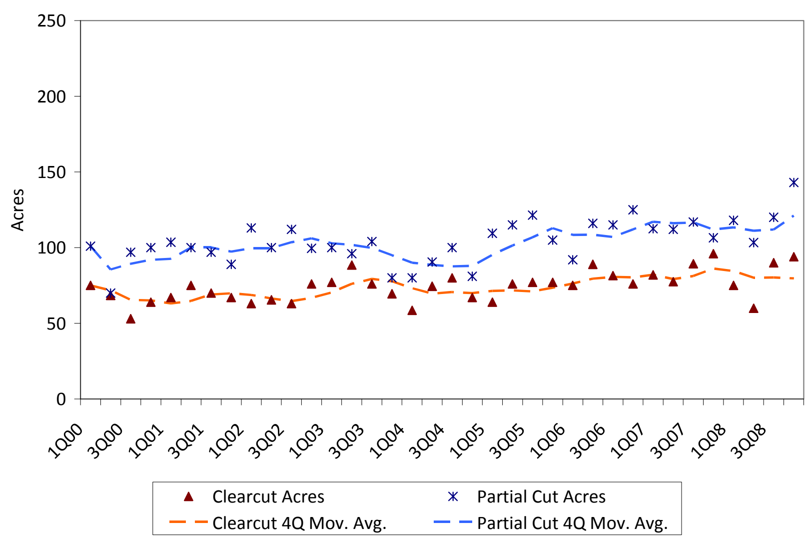

Figure 2. Median clearcut and partial cut acreage in the Southeastern US between 2000 and 2008.

Total volume harvested per tract fluctuated more than other measures over the period studied, but again few trends were apparent over the entire timeframe (Figure 3). Through 2003 and 2004, a distinct peak is seen where total tract volume was higher for clearcuts and to a lesser extent for partial harvests. Median partial harvest volume ranged between 1300 tons and 5300 tons for a given quarter. Median clearcut harvest volume ranged between 2500 tons and 8000 tons. Both of these ranges are extremely wide considering they are median values for a quarter.

Despite the observed variation in total harvest volume, median per acre volume harvested remained stable through 2005, after which clearcut per acre volumes began to fluctuate substantially (Figure 4). Partial harvest volumes per acre have stayed close to 30 tons since 2000, only once increasing above 40 tons per acre and twice decreasing beneath 25 tons per acre. Excluding the first quarter of 2008, which is believed to be an anomalous value resulting from low reporting volumes, per acre clearcut volumes have fluctuated between roughly 50 and 80 tons, dipping below 50 tons on only one other occasion.

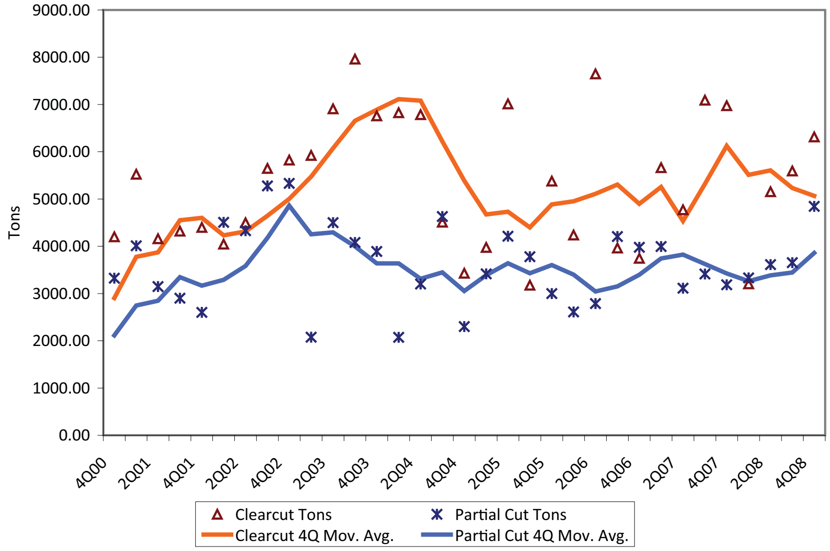

Figure 3. Median and four-quarter moving average total harvest volume per tract in tons for clearcuts and partial harvests from October 2000 through December 2008.

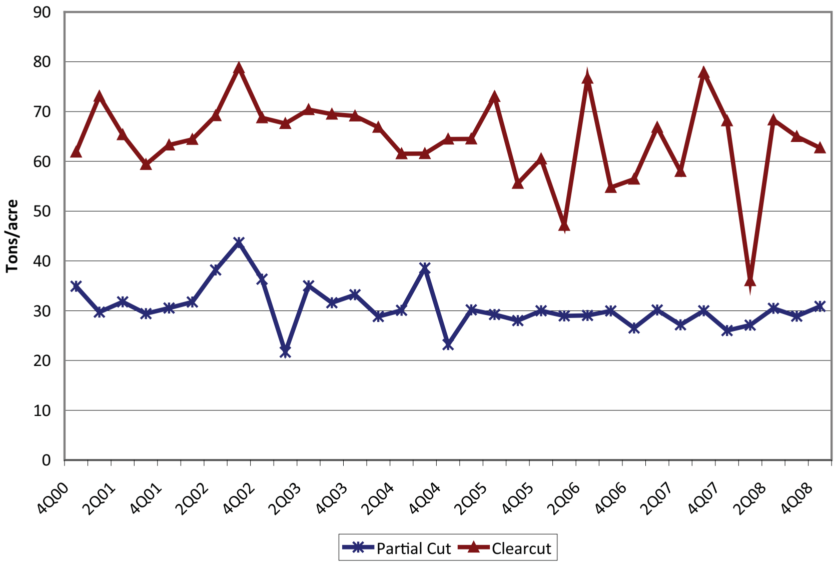

Figure 4. Median tons harvested per acre for clearcuts and partial harvests from October 2000 through December 2008.

We analyzed the observed ranges in harvested tract data using the Auburn Harvesting Analyzer to determine the sensitivity of the model to each variable of interest. When harvested acreages, quadratic mean diameters, or tons per acre were at low values, per ton logging costs increased rapidly (Figure 5). As the values of these variables each increased, per ton costs declined. Beyond some point, production reached a practical maximum in the given set of stand conditions, and costs decreased at a gradual rate as variable costs and tract fixed costs (e.g. road construction costs) per ton decreased incrementally.

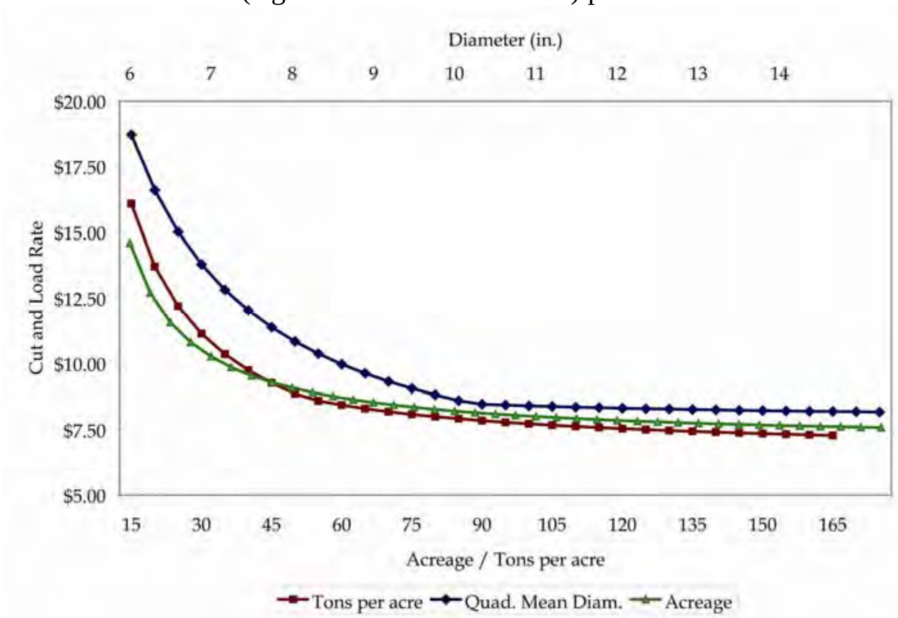

Figure 5. Modeled impact of changes in tons per acre harvested, quadratic mean diameter, and acreage on per ton cut and load rate.

When the average tract characteristics from Chapter 1 were used in the cost model, few trends were apparent in the data with regards to cost impacts over the period studied (Figure 6). The higher rate for partial cuts was a result of a smaller average tree size and fewer tons harvested per acre. The implication appeared to be that shifts in the characteristics of harvested tracts have not had a large impact on average harvesting costs across the Southeast. While quarterly fluctuations have been high at times, the long-term average has not shifted appreciably. Other researchers have found substantial cost increases for harvesting contractors over the same timeframe (e.g. Stuart *et al.* 2008). These data suggest that harvesting cost increases would be driven by shifts in component costs (e.g. labor, fuel, etc.), as reported by Stuart, *et al.* (2008), more so than changes in tract characteristics.

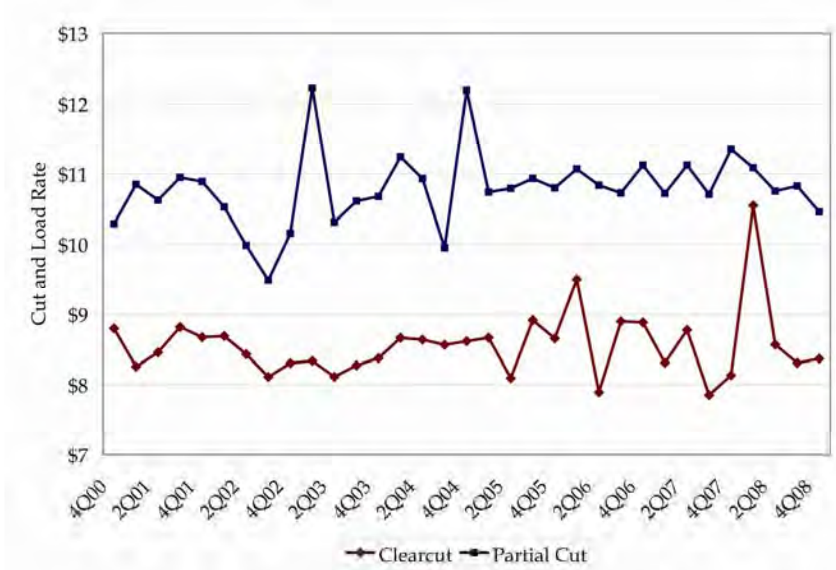

Figure 6. Quarterly changes in modeled cut and load rates based on average harvest tract characteristics from the 4th quarter 2000 through 4th quarter 2008.

Acknowledgements

This research was funded by a grant from the Wood Supply Research Institute. The authors also wish to acknowledge Timber-Mart South, who provided the data used to complete this project.

Literature Cited

Baker, S.A. and W. D. Greene. 2008. Changes in Georgia's logging workforce, 1987-2007. *So. J. Appl. For.* 32(2): 60-68.

Harris, T. G., J. Smith, R. Simmons and S. Baldwin. 2009. Timber Mart-South Publications: Fourth Quarter 2007. Timber Mart-South, Vol. 33, No. 4; Athens, GA.

Hollander, M. and D.A. Wolfe. 1999. *Nonparametric statistical methods.* John Wiley and Sons Inc., New York, New York. 787 p.

Stuart, W.B., L.A. Grace, C.B. Altizer, and J.J. Smith. 2008. 2006 Preliminary Logging Cost Indices. Wood Supply Research Institute. Forest and Wildlife Research Center, Starkville, MS. #FO387. 14pp.

Tufts, R.A., B.L. Lanford, W.D. Greene, and J.O. Burrows. 1985. Auburn harvesting analyzer. The COMPILER Forest Resources Systems Institute, Florence, AL. 3(2):14-15.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

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Paper Title:
Characteristics of Logging Businesses Currently Harvesting Biomass for Energy in the Piedmont of Virginia

ABSTRACT
Like many areas of the country, Virginia has witnessed an increasing interest in potential projects utilizing woody biomass for energy. However certain areas of the piedmont region of Virginia currently have significant biomass markets which have existed for well over a decade and many logging businesses have adapted their operations to harvest biomass in addition to conventional roundwood products. Located within the piedmont of Virginia are an 85 MW wood fired power plant along with two paper mills which procure boiler fuel on the open market. These three facilities result in an estimated combined consumption of over a million tons of biomass per year in this region. In the summer of 2009, we completed a mail survey of Virginia Logging businesses using the database of participants in the VA SHARP Logger program. Survey results indicate that within the piedmont of Virginia, 16% of all logging businesses are currently producing biomass in the form of fuel chips. Logging businesses harvesting biomass tend to be more mechanized, have higher total production levels, more crews per business, and more workers per crew than the average logging business in the region. However there is still a broad range in production levels among biomass harvesting businesses, ranging from a minimum of six to a maximum of one hundred loads per week per crew. The most common type of harvest performed by biomass harvesting businesses was hardwood clear cuts, followed by pine clear cuts, pine thinning, and hardwood select cuts. Survey results indicate that when competitive biomass markets exist, a broad range of logging businesses will see the value of biomass harvesting to their business and respond to produce biomass for energy in addition to conventional roundwood products.

INTRODUCTION
Like many areas of the nation, interest in biomass utilization in Virginia is increasing. Virginia currently has a significant forest industry with a total annual impact of $23 billion to the state (Rephann 2008). Certain parts of the state have competitive biomass markets that have existed for more than a decade and have allowed loggers to adapt and respond to biomass markets as another market for the products they harvest. Located within the piedmont of Virginia is an 85

MW, 100% biomass fired electrical generation facility operated by Dominion Virginia Power near Hurt, VA. Additionally there are two paper mills which procure boiler fuel on the open market to provide energy for their manufacturing processes. The estimated combined biomass utilization capacity of these three facilities is in excess of one million tons per year, a substantial portion of which comes from in-woods production of biomass in the form of whole tree chips from logging operations.

Virginia's SHARP logger program is recognized as meeting the Sustainable Forestry Initiative (SFI) logger training requirements and is coordinated as a VA Tech Forest Operations Extension Program in the Virginia Tech Department of Forest Resources and Environmental Conservation. While Virginia has an active logging workforce and an active logger training program, a comprehensive survey of Virginia loggers has never been completed. Similar surveys have been completed in the past (Moldehauer and Bolding 2009, Egan 2009, Baker and Greene 2008, Milauskus and Wang 2006, Egan and Taggart 2004) to characterize logging workforces in other states. The objective of this study was to characterize Virginia loggers, collect information to assist with developing educational programs, and to assess the extent to which Virginia's logging contractors are responding to markets to produce woody biomass for energy in an area with competitive and well established markets for woody biomass.

METHODS

A questionnaire was developed to collect information about Virginia SHARP logger program participants and gather additional information about Virginia logging contractors and their business operations including biomass harvesting. Questionnaires were mailed to all current Virginia SHARP Loggers during the summer of 2009 following a modified Dillman method (Dillman 2000). The mailing list consisted of 1,590 individuals who were current SHARP Loggers. This list included loggers, foresters, and others who had completed the SHARP Logger program. The survey form consisted of two sections. Everyone was asked to complete the first section of the questionnaire to collect general information on SHARP logger program participants. Only logging business owners were asked to complete the second part of the questionnaire which asked for more detailed information on their logging business. The questionnaire asked logging business owners questions related to their harvesting operation characteristics, owner demographics, and whether or not they currently harvested biomass in the form of "fuel chips".

RESULTS AND DISCUSSION

Of the 1,590 surveys mailed, twenty one were removed from the population after being returned with invalid addresses, resulting in a survey population of 1569 individuals. Nine Hundred twenty two surveys were returned for a response rate of 58.8 %. Four hundred eighty eight of the 922 survey responders indicated that they were the owner of the logging business. Two hundred forty of the 488 logging business owners indicated that they operated primarily in the piedmont region of Virginia based on the U.S. Forest Service classification of Virginia's physiographic regions (Figure 1) (Cooper and Becker 2009). Thirty eight of the 240 piedmont logging businesses indicated that they were currently harvesting biomass. These thirty eight logging businesses which are operating in the piedmont of Virginia are further analyzed to determine additional information on their harvesting operation characteristics and how they have responded to biomass harvesting.

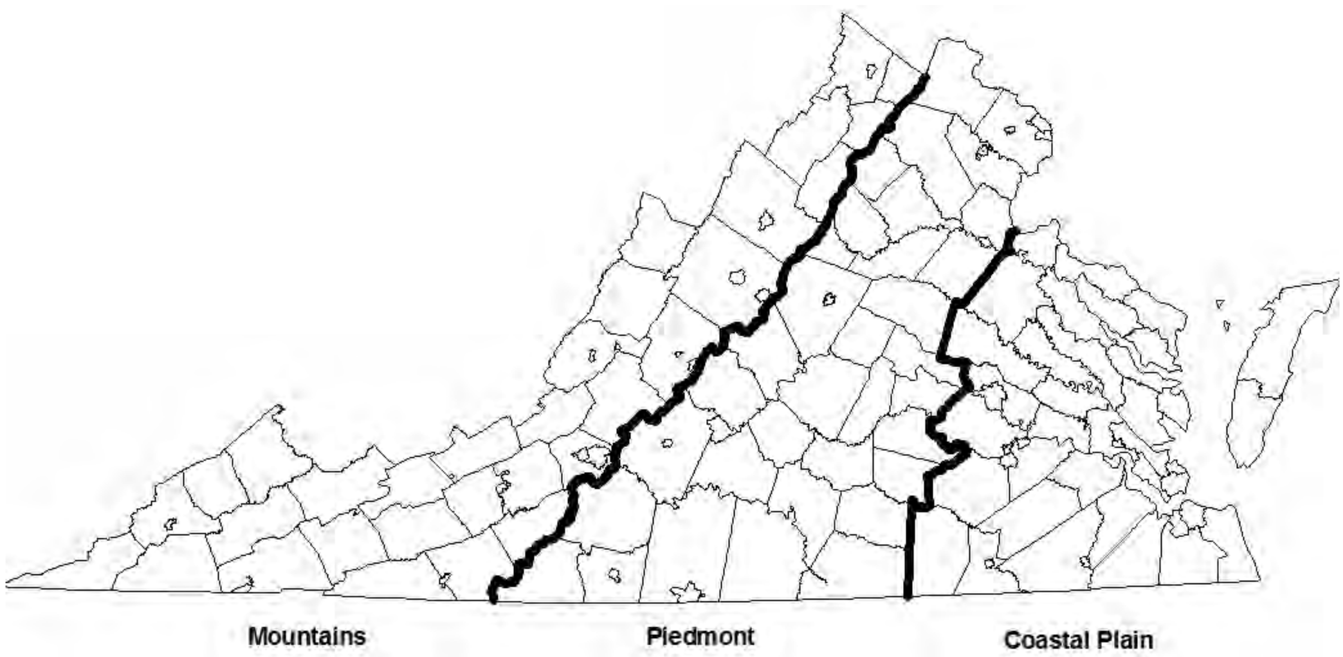


Figure 1: Three physiographic regions of Virginia as defined by the USFS (Cooper and Becker 2009)

Business Owner and Operational Characteristics

Responses from owners of biomass harvesting operations indicate that 97% of business owners are Caucasian, 3% are African American, and 100% indicated they were males. The average age of biomass harvesting business owners was 47.7 years old which was slightly younger than the overall average age of loggers in the piedmont which was 49.1 years old. For owners of biomass harvesting businesses, 37.8% indicated they had not completed high school, 45.9% were high school graduates, 5.4% attended but did not complete college, and 10.8% indicated they were a college graduate.

The questionnaire asked logging business owners to indicate which method they most commonly used for each of the harvesting, processing, and transportation functions in their logging system (Table 1). They were asked to circle the response that represented the single most common means they used for that task. In some cases they circled more than one response which resulted in the category in Table 1 labeled “multiple” indicating multiple responses. Eighty nine percent of biomass harvesting operation in the piedmont are felling with rubber-tired feller bunchers and 100% are using grapple skidders. Sixty-eight percent are delimbing with pull through delimbers and 13% are delimbing with a chain flail delimber. Ninety one percent of biomass harvesters indicated they are bucking logs with a buck / slasher saw. Loading is accomplished almost entirely with a trailer mounted knuckle boom loader and trucking is almost exclusively by tractor and trailer.

Table 1: Logging business owner responses for the most commonly used method for harvesting, processing, and transportation functions of all piedmont logging businesses and piedmont biomass harvesting businesses.

		All Piedmont loggers % responses	Piedmont biomass harvesters only % responses
Felling			
	Chainsaw	36	3
	Rubber tired Feller-Buncher	54	89
	Tracked Feller-Buncher	1	3
	Cut-to-length Harvester	1	0
	Multiple	8	5
Skidding			
	Cable skidder	19	0
	Grapple skidder	64	100
	Forwarder	1	0
	Bulldozer	1	0
	Multiple	15	0
Delimbing			
	Chainsaw	40	3
	Delimbing Gate with Pull-through Delimber	5	5
	Pull-through Delimber	45	68
	Chainflail Delimber	4	14
	Stroke Delimber	1	3
	Multiple	5	7
Bucking			
	Chainsaw	24	3
	Buck / Slasher Saw	72	91
	Swing-Boom Processor	1	0
	No Bucking	1	3
	Multiple	2	3
Loading			
	Trailer Mounted Knuckleboom	76	97
	Mobile knuckleboom	10	3
	Self Loading Trucks	1	0
	Front end Loader	8	0
	Multiple	5	0
Trucking			
	Tractor Trailer	62	97
	Single Axle	11	0
	Tandem Axle	12	0
	Tandem with Pup Trailer	2	0
	Tri-Axle	5	0
	Tri-Axle with Pup Trailer	2	0
	Multiple	6	3
Chipping			
	Whole Tree Chipper (dirty chips)	16	90
	Whole Tree chipper with Flail (clean chips)	1	5
	Horizontal or tub Grinder	0	0
	Multiple	2	5
	No Chipper	81	0

Production of biomass in the woods is generally accomplished by adding a whole tree chipper to an existing conventional harvesting operation. Ninety percent of biomass harvesters indicated they primarily produced biomass using a whole tree chipper to produce dirty or fuel chips. Five percent indicated that their chipping was primarily with a chipper with a chain flail producing clean chips. For these operations, biomass production is likely from residues of their clean or "pulp quality" chipping operation. None of the biomass harvesters responding to the survey indicated they most commonly used only a grinder to produce biomass. As compared to all harvesting operations in the piedmont, biomass harvesting operations are much less likely to use chainsaws for felling, delimbing, or bucking. While there is considerable variation in loading and trucking methods among all loggers in the region, biomass harvesting operations rely almost exclusively on trailer mounted knuckle boom loaders and tractor and trailer combinations for trucking.

Productivity and Biomass Harvesting

Average weekly production per crew from biomass harvesting operations (Table 2) ranged from 6 loads to 100 loads per week with an average of 31.46 loads per crew per week. On average, biomass harvesting operations owned 1.32 crews per business and ranged from 1 crew to a maximum of 4 crews. Biomass harvesting operations had an average of 3.92 workers per crew and ranged from a minimum of 1 to a maximum of 8 workers per crew. Compared to all logging businesses in the piedmont, biomass harvesters tend to be higher production, have more crews per business, and more workers per crew.

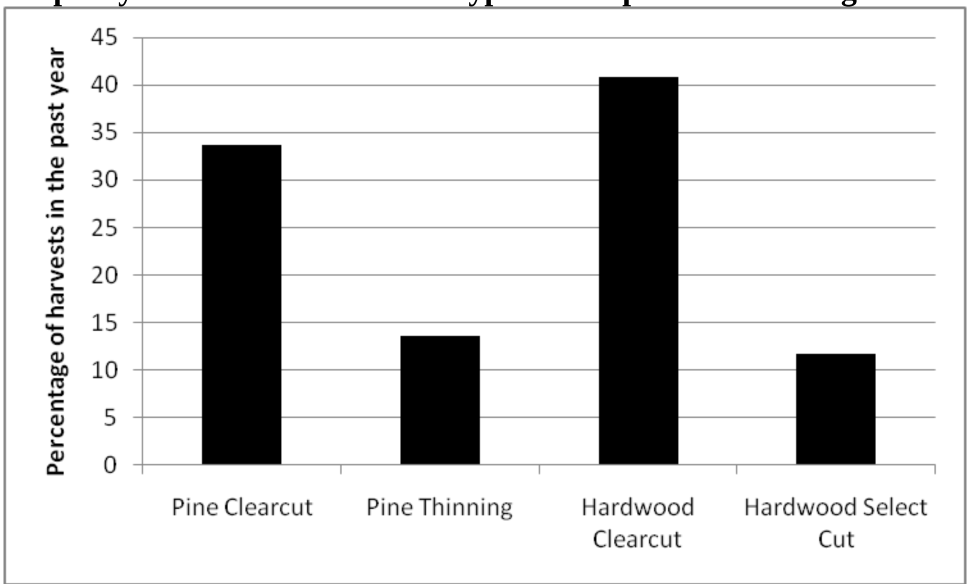
Table 2: Descriptive statistics of average production, number of crews, and crew size of biomass harvesting operations and overall average of piedmont logging businesses.

	Count	Mean	Minimum	Maximum	SD
Piedmont biomass operations					
Loads per crew per week	37	31.46	6	100	21.58
Crews owned	38	1.32	1	4	0.66
Workers per crew	38	3.92	1	8	1.32
Piedmont – all operations					
Loads per crew per week	209	22.41	2	100	18.43
Crews owned	209	1.12	1	4	0.38
Workers per crew	207	3.31	1	10	1.63

The questionnaire asked logging business owners to estimate the percentage of their logging jobs in the past year that were of the following harvest type; pine clearcut, pine thinning, hardwood clearcut, or hardwood select cut. The most common type of harvest reported was hardwood clearcut 41% (Figure 2) followed closely by pine clearcuts 34%. The variety of pine and hardwood harvesting operations indicates that loggers are able to productively harvest biomass for fuel in both pine and hardwood harvests. Biomass harvesting businesses were also asked to estimate the percent by volume of their total production that was in the form of dirty / fuel chips.

The overall average percentage of fuel chips produced was 19.6 % of total production and responses ranged from 1% to 70 % of total production.

Figure 2. Biomass harvesting business owner responses for percentage of logging jobs in the past year of different harvest types in the piedmont of Virginia.



CONCLUSION

The piedmont of Virginia represents a region with an active traditional forest products industry as well as a competitive and well established biomass market. Within this market, 16 % of logging businesses responding to our survey indicated they have responded to the market for biomass and are producing biomass for energy in addition to conventional forest products. When compared to the averages of all logging businesses within the Piedmont, biomass harvesting businesses tend to be larger firms that are more mechanized and have higher production levels. Biomass harvesting operations also tend to have a larger number of employees, and the business owner is more likely to have multiple crews. However, biomass harvesting businesses occur across the size and productivity spectrum with production levels from 6 to 100 loads per week and crew sizes from 1 to 8 workers.

This survey indicates the extent to which loggers are willing to respond to biomass markets and add a chipper to their operation to harvest biomass for energy when competitive markets are available. The results of this survey indicate that there may be some operational limitations on the types of harvesting systems for effectively harvesting biomass in this particular region and market. For example, biomass harvesting is primarily limited to operations with mechanized felling, delimbing, and bucking. However logging businesses of many sizes and productivity levels have seen the value that biomass harvesting can bring to their business and have made the decision to integrate biomass harvesting into their conventional harvesting systems.

Works Cited

Baker, S. and W.D. Greene. 2008. Changes in Georgia's Logging Workforce, 1987-2007. Southern J. of Applied Forestry. 32(2):60-68.

Cooper, J.A. and C.W. Becker. 2009. Virginia's timber industry—an assessment of timber product output and use, 2007. Resour. Bull. SRS-155. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 33 pp.

Dillman, DA. 2000. Mail and internet surveys: The tailored design method. New York: John Wiley and Sons. 480 pp.

Egan, A. 2009. Characteristics of New York's Logging Businesses and Logging Business Owners. Northern J. of Applied Forestry. 26(3):106-110.

Egan, A. and D. Taggart. 2004. Who Will Log in Maine's North Woods? A Cross-Cultural Study of Occupational Choice and Prestige. Northern J. of Applied Forestry. 21(4):200-208.

Milauskas, S and J. Wang. 2006. West Virginia Logger Characteristics. Forest Prod. J. 56(2):19-24.

Moldenhauer, M.C. and M.C. Bolding. 2009. Parcelization of South Carolina's Private forestland: Loggers' Reactions to a Growing Threat. Forest Prod. J. 59(6):37-43.

Rephann, T.J. 2008. The Economic Impact of Agriculture and Forestry on the Commonwealth of Virginia. Weldon Cooper Center for Public Service. University of Virginia. 56 pp.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Developing Woody Biomass Retention Guidelines in Maine

Jeffrey G. Benjamin[1], Donald J. Mansius[2], Kate Albert Read[3]

Abstract

Woody biomass retention guidelines have been developed for Maine's forest industry as part of a two-year effort led by the University of Maine, Maine Forest Service, and the Trust to Conserve Northeast Forestlands. The initiative involved a multi-stakeholder consultation process and a review of scientific studies relevant to impacts from biomass harvesting. The objectives of this paper are to: 1) describe the guideline development process, 2) summarize the final guidelines, and 3) identify future work related to implementation.

The guidelines are intended for use by loggers, foresters, and landowners to protect soil, water quality and biodiversity on timber harvesting sites in Maine. They can be adapted and included in site-specific recommendations developed by a licensed forester and they are intended to inform the landowner's decision-making while reviewing the forester's prescription. Most importantly, implementation of these practices on the ground depends on the professional judgment, knowledge, and skill of the logger conducting the harvest operation. Every acre of forest cannot be managed the same way and the guidelines should not be interpreted in that manner. The guidelines address elements of forest structure related to soil, water quality, and biodiversity. These elements include snags, wood of all sizes left on the forest floor, live cavity trees and mast-producing trees. The guidelines are applicable to any harvest operation, but they may be of greatest importance on harvests where woody biomass is a significant component of the product mix.

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Introduction

Federal energy policies to reduce dependence on foreign oil have created opportunities to produce energy from wood. These initiatives prompted some states, such as Minnesota and Wisconsin, to develop woody biomass harvesting guidelines to proactively address environmental concerns with increased harvest levels. Harvest of woody biomass in Maine is not a new concept. In fact, bioenergy facilities that produce electricity by burning wood are common throughout the state and many have been in operation since the 1980s. Some are stand alone facilities and others are integrated within pulp and paper mills. During that time, guidelines specific to woody biomass harvesting were missing from existing best management practices and regulations.

There has also been an increase in wood-for-energy initiatives throughout Maine over the last few years. In fact, biomass chip harvests have increased dramatically since 2000 (Figure 1) and that trend is expected to continue given plans for new and expanded capacity in the region for wood pellets, bioenergy, and bioproducts. We do not know the impact these new initiatives will have on wood supply, but it is certainly possible that competition for raw material between wood-using facilities will increase. Increased competition may impact harvest levels through shorter rotations, or increased use of small diameter and poor quality stems. This may create opportunities for timber stand improvement by combining such harvests with conventional forest management and silvicultural treatments. Regardless of the outcome, there is concern that these and other related activities will put more pressure on our forests (Benjamin *et al.* 2009, Marciano *et al.* 2009).

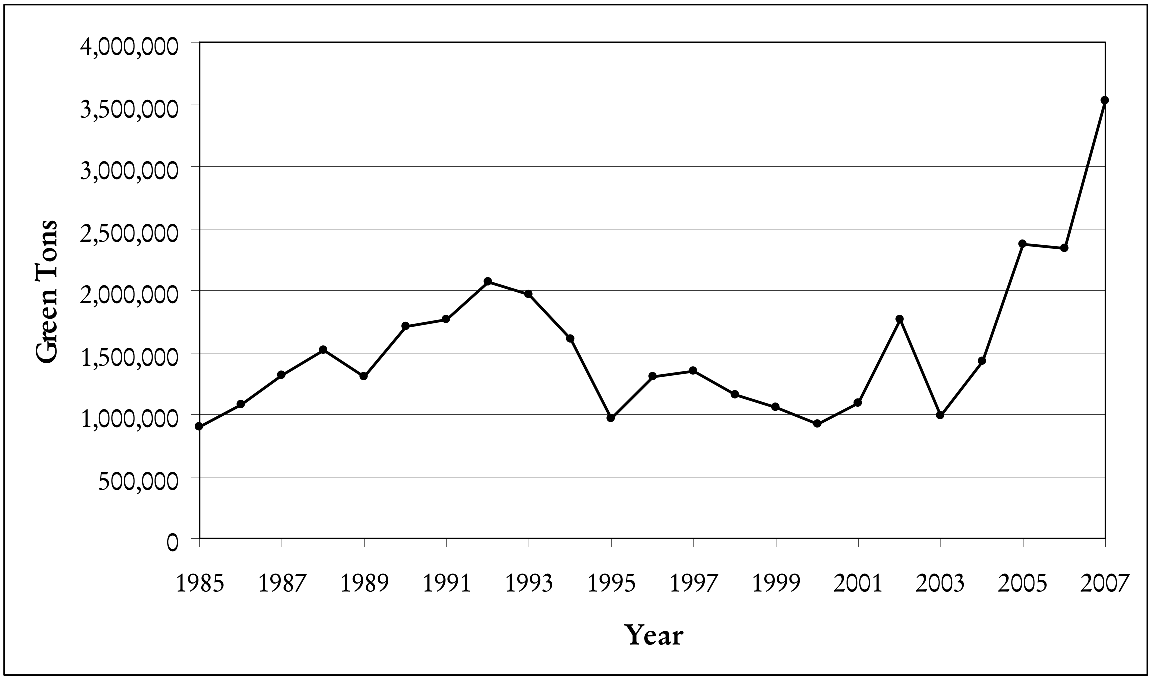

Figure 1. Historic biomass chip harvest levels in Maine (Maine Forest Service 2008).

In 2007, an initiative led by the University of Maine, in collaboration with the Maine Forest Service, and the Trust to Conserve Northeast Forestlands, was undertaken to proactively address some environmental concerns related to biomass harvests within Maine's forest industry. The goal was to develop a set of voluntary guidelines to assist loggers, landowners, and foresters in protecting soils, water quality, and forest biodiversity with respect to retention of woody biomass during forest operations. The objectives of this paper are to: 1) describe the guideline development process, 2) summarize the final guidelines, and 3) identify future work related to implementation.

Development Process

The initiative involved a multi-stakeholder consultation process representing views of foresters, landowners, wood using facilities, loggers, and conservation groups. A technical committee was established to review scientific studies relevant to environmental impacts associated with biomass harvesting. This review formed the basis of a technical report from which specific guidelines for woody biomass retention were developed. External reviews were conducted by respected professionals working in the fields of soil science, water quality and biodiversity. This was an iterative process between all parties and many versions of the document were circulated and reviewed during the course of the work. The final guidelines represent the collective effort of many individuals with often diverse perspectives of Maine's forest industry. As a result, not everyone is in agreement with all aspects of the recommendations, but the work was undoubtedly improved with the consultative approach. Final deliverables included a technical report to provide context for the project and to summarize findings from the literature review, and a brochure-style summary of the site-specific guidelines[4].

Summary of Guidelines

Scope

The first challenge for the technical committee and stakeholders was to establish the scope of work. Throughout the process decisions were made regarding definitions, target audience, scale (site-level or landscape), focus (harvest or retention), and format (prescriptive or general). Woody biomass was defined from a forest operations perspective to be comprised of logging residues, previously un-merchantable stems, and other such woody material harvested directly from the forest typically for the purposes of energy production. Harvest of woody biomass is often integrated with traditional forest operations, so it can be difficult to isolate effects of woody biomass removals at a site level. As such, it is important to consider retention of woody biomass during all harvest activities and to emphasize post-harvest site condition rather than the amount of any given product removed during harvest.
In their final form, the guidelines focus on the amount and type of woody biomass that should be retained in the forest after a harvest operation to protect soil productivity, water quality, and site-level biodiversity.

Every acre of forest cannot be managed the same way and the guidelines should not be interpreted in that manner. The guidelines address elements of forest structure including snags, wood of all sizes left on the forest floor, live cavity trees and mast-producing trees. Although the guidelines are applicable to any harvest operation, they may be of greatest importance on harvests where woody biomass is a significant component of the product mix. Fundamentally, logging contractors do not treat woody biomass differently than other forest products – it is simply another product sorted at the landing – so the same general principles of forest operations apply.

Recommendations for retention of woody biomass should be used in conjunction with rules and regulations, environmental standards, and best management practices already established for traditional operations. These practices and policies can be adapted and included in site-specific recommendations developed by a licensed forester, so the guidelines developed in this project are intended to inform the landowner's decision-making as they review the forester's prescription. Most importantly, implementation of these practices on the ground depends on the professional judgment, knowledge,

[4] Refer to the publications link at: www.forest.umaine.edu/faculty-staff/directory/jeffrey-benjamin/

and skill of the logger conducting the harvest operation. These guidelines are intended to be used by loggers, foresters, and landowners in this context.

Soils

A review of scientific literature related to forest soils was conducted with particular emphasis on soil productivity studies from the northeastern region of the United States. Several long-term studies – including Hubbard Brook Experimental Forest in New Hampshire and the Weymouth Point Study Area in Maine – formed the basis of the review (Likens *et al.* 1970, Smith *et al* 1986, Hornbeck *et al.* 1990). The review summarized nutrient and biomass distribution in trees, and highlighted short-term and long-term effects of whole-tree harvesting on nutrient depletion. The following section highlights the key findings related to soil productivity and a complete list of soil related guidelines is provided in Appendix A.

Forest soils are complex biological, chemical, and physical systems. Soil productivity is directly related to nutrient availability which depends on factors such as minerals in the parent material, rates of mineral weathering, leaching losses and erosion, past land use, atmospheric deposition, vegetation composition, rotation length, rate of tree growth and harvest intensity. Nutrient amounts removed in biomass from whole-tree operations are much greater than nutrient amounts removed from conventional stem-only harvesting. This is because, as shown in Figure 2, nutrient concentrations are much higher in branches and particularly in needles and leaves, and therefore a much larger portion of the total biomass nutrients is removed when branches and foliage are included in the harvest removal (Young and Carpenter 1976). The more fine woody material that is left on site during harvest operations, the less risk there is to long-term soil productivity.

Not all soils are created equal. Higher quality forest sites tend to have a higher natural nutrient supply and they cycle nutrients more rapidly. The greater the nutrient supply, and the faster the rate of nutrient transformation into available forms, the lower the risk that harvesting will reduce soil productivity as long as there are no other limiting factors of greater importance on the site. This means that for a given level of biomass retention, the risk to soil productivity is lower on higher quality sites.

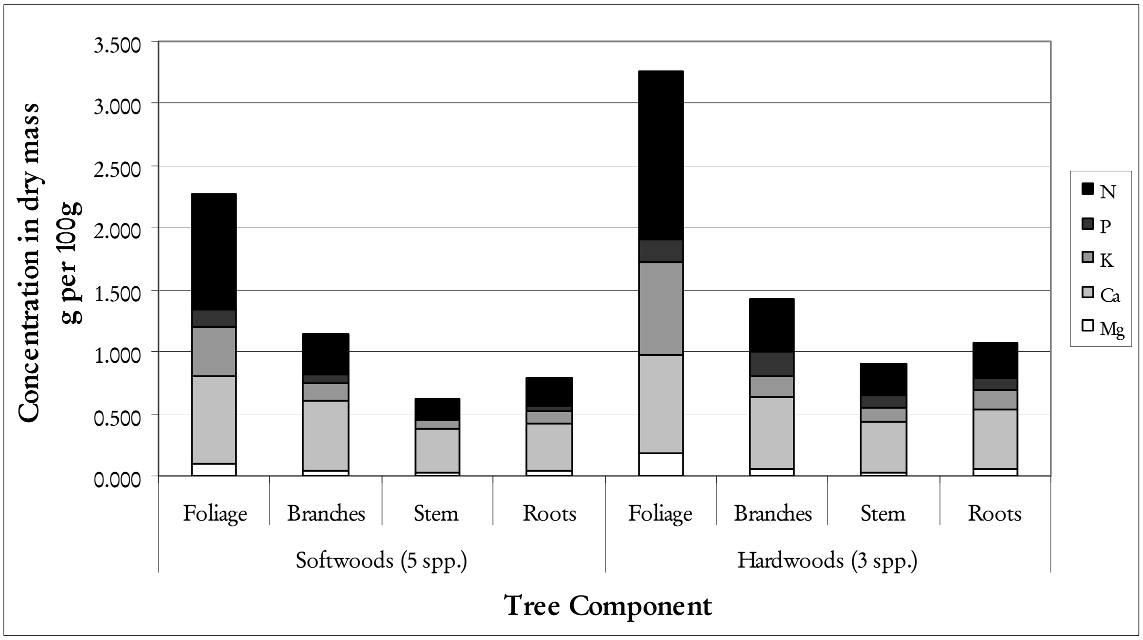

Figure 2. Average concentration of macro-nutrients in foliage, branches, stems, and roots of young hardwood and softwood species in Maine (*Young and Carpenter 1976*).

Forest soils produce excess nutrients through mineral weathering and organic matter decomposition as part of the natural function of the soil, and these excess nutrients beyond vegetation requirements are typically leached from the site. Increased nutrient removals through harvesting that are less than or equal to these excess nutrients should not alter forest site productivity. If harvesting results in nutrient removals that exceed these excesses, then forest soil nutrient availability will decline. By avoiding the intensification of biomass removals on soils with characteristics that suggest limited nutrient amounts (e.g., shallow soils) or slow rates of nutrient supply (e.g., sandy soils), we also avoid the risk of reducing site productivity through harvesting. Although it is possible to restore nutrient supply in a forest soil in some circumstances by increasing rotation length or altering species composition, short-term improvements in nutrient availability can only be achieved through the application of fertilizers, biosolids, or other soil manipulations.

In conducting research for this section, it was found that most of the studies on whole-tree harvesting utilize the method of whole-tree clearcutting. Yet, less than 5% of harvests in Maine were categorized as clearcuts or land use changes between 2002 and 2007 (Maine Forest Service 2009). Clearcutting represents a more severe disturbance and maximizes soil nutrient loss through increased soil leaching and erosion. Therefore, the results of soil productivity studies focusing on whole-tree clearcut harvesting may suggest a more severe impact than the current silviculture systems currently employed in Maine (e.g. thinning and partial harvests). On the other hand, while clearcutting may represent a larger overall disturbance to a site, partial harvesting, in general, allows more wood to be extracted in a given period of time because partial cuts do not require buffers or separation zones (Hagan and Boone 1997). It is likely, however, that whole-tree clearcutting provides the most conservative basis with which to judge the environmental impacts of increased biomass harvesting since all merchantable vegetation is removed from the site. Therefore, while the results of these studies are severe, they are still relevant in illustrating the relationship between amounts of biomass extraction and nutrient retention.

Water Quality

The Maine Forest Service's Best Management Practices for Forestry is a program that focuses on education, outreach, and voluntary measures to protect water quality during timber harvesting activities (Maine Forest Service 2004). The program now includes monitoring protocols to determine the use and effectiveness of BMPs on timber harvesting operations within the state. As shown in Table 1, recent years have shown significant improvement in BMP use and effectiveness. In 2000, BMPs were not used on 25% of harvests, but by 2008 compliance increased by close to 20% in total.

Table 1. Comparison of BMP use from 2000 to 2008 (*Maine Forest Service 2009*).

Reporting Period	Sampling Units	Appropriate BMP Use (%)	Non-application of BMPs (%)
2000-2001	181	41	25
2001-2003	288	52	8
2005	102	79* (92**)	4* (6**)
2006-2007	252	77*	4* (2**)
2008	122	72* (92**)	4* (2**)

* Crossings ** Approaches

Due to the success of the water quality program in Maine, this section of the guidelines only serves as a reminder about several important aspects of water quality as it relates to the amount of woody biomass retained on harvesting sites, but it is not intended as a replacement of existing Water Quality BMPs. In one of the few studies directly related to the impact of woody biomass harvesting on water quality, Shepard (2006) concludes that since woody biomass is often harvested in conjunction with other round wood forest products, existing BMPs for any harvest can be followed to protect water quality. A complete list of water related guidelines is provided in Appendix A.

The University of Maine has been involved with water quality research for many years. In 1996, the Water Research Institute prepared a report for the Maine Department of Environmental Protection to review the effects of forest practices on water quality in Maine (Kahl 1996). That same year, the Cooperative Forestry Research Unit also completed a literature review of forestry related non-point source pollution in Maine (Stafford *el al.* 1996). Both Kahl (1996) and Stafford *et al.* (1996)

closely examined the impact of forest practices in relation to water quality and also the use of best management practices to mitigate undesirable consequences. They focused primarily on regional studies that were applicable to Maine including the Hubbard Brook Experimental Forest in New Hampshire and the Weymouth Point Study Area in Maine. Both reports provide detailed descriptions of the relationships between harvest practices and many issues important to water quality including site disturbance, hydrology, nutrient cycling, stream temperature, and stream flow. Kahl (1996) in particular points out that the level of site disturbance from harvest activities is related to both harvest intensity and compliance with best management practices, but in general harvesting has the potential to reduce long-term site productivity as well as to decrease water quality. He summarizes that harvesting impacts nutrient cycling and water quality in three ways due to removal of nutrients in the harvested material, decreased uptake of nutrients and water, and changes to biogeochemical processes. The latter is linked to increased runoff of nutrients and sediment caused by soil compaction, rutting, increased stream temperature, and altered hydrology. None of these issues are unique to woody biomass harvests, rather they apply to timber harvesting in general, so as long as water quality BMPs are followed there should be no additional impact with woody biomass removals.

Forest Biodiversity

Timber harvesting can be a tool used to manage wildlife habitat values and, if carefully planned, it is compatible with most aspects of biodiversity. As with other forest resources, the potential risk to biodiversity increases with the amount and type of woody biomass removed from a site and with the frequency of such removals (Whitman and Hagan 2007, Vaillancourt *et al.* 2008). Therefore, high rates of woody biomass removal can negatively affect forest biodiversity. The following section highlights the key findings related to forest biodiversity and a complete list of soil related guidelines is provided in Appendix A.

For this section, an emphasis was placed on studies that identified the impact of woody biomass harvesting on biodiversity. Many studies are concerned that biomass harvesting will lead to agriculture-like conversions of forestlands or levels of harvesting that will extensively alter current habitat conditions. Much research has been conducted over the last 20 years in regard to forest biodiversity specific to the northeast United States, but it also covers highly diverse regions such as tropical rainforests and old growth forests (Hansen *et al*. 1991, Putz *et al*. 2001) and recent studies of forest structure from other geographic regions like the Pacific Northwest (Dunk and Hawley 2009), Canada (Vaillancourt 2008), and Nordic countries (Roberge *et al.* 2008). As important as those issues are, only a small number of papers were found that attempted to postulate the impacts to biodiversity from woody biomass harvesting specifically.

It is also important to place forest management concerns related to biodiversity into context with the existing forest industry in Maine. Between 2002 and 2007, over 50% of all harvests were conducted as partial harvests, and less than 5% were categorized as clearcuts or land use changes (Maine Forest Service 2009). Maine's forest industry also relies heavily on natural regeneration. An average of 40% of all harvests between 2002 and 2007 were classified as shelterwood harvests (Maine Forest Service 2009), and between 1996 and 2007 less than 2% of harvested acres were planted (Maine Forest Service 2009). Clearly Maine has not succumbed to vast agriculture-like conversions of forestland into monoculture energy plantations even with an energy wood market since the 1980s.

The amount and type of woody biomass removed from a harvest site is highly dependent on the harvest method and equipment used. Whole-tree harvesting is the dominant harvest method in Maine with over 85% of harvested areas using ground-based skidding systems in the last four years (Benjamin 2009). Although this type of harvest delivers tops and limbs of merchantable trees to roadside for processing into energy wood, the amount of timber removed from a site varies with silvicultural prescription and landowner objectives. The equipment in use today is not designed to efficiently handle and process small diameter stems, snags, or other such downed woody material which has been described earlier to hold special habitat value. Specialized woody biomass accumulation technologies are commercially available and include slash bundlers, residue compaction units, and mobile chippers, but to date their use has not proven to be cost effective in Maine.

Notwithstanding the observations made in the previous two paragraphs, timber harvesting in Maine, and removal of woody biomass in particular, does have implications on forest biodiversity. The goal of this section is to highlight the important aspects of woody biomass as it relates to forest biodiversity and to remind practitioners to plan harvests with those features in mind. Fortunately, much work has already been completed for the forests of Maine in this regard. Woody biomass harvesting practices will have to comply with established recommendations for biodiversity as defined for non-biomass harvests.

A comprehensive manual outlining recommended guidelines for maintaining biodiversity in the forests of Maine was originally published by Flatebo *et al.* (1999) and many of the general recommendations in Appendix A were summarized from the updated version by Elliot (2008). One of the primary goals for biodiversity in Maine's managed forest is to ensure that adequate habitat is present to maintain viable populations of native plant and animal species. Recommendations are written for site-specific characteristics covering five stand characteristics and 10 special habitats and ecosystems (including riparian and stream ecosystems, vernal pools, beaver-influenced ecosystems, woodland seeps and springs, nesting areas for colonial wading birds, deer wintering areas, nesting sites for woodland raptors, old-growth and primary forests, rare plant or animal sites, and rare natural communities). Stand-level recommendations are related to vertical structure and crown closure; native species and composition; downed woody material, snags, and cavity trees; mast; and forest soils, forest floor and site productivity.

The guidelines by Elliot (2008) also address landscape-level considerations which focus on patterns, processes and linkages across landscapes and regions. They address the distribution of native forest communities, age structure of the landscape, habitat patch size, habitat connectivity, disease agents, insects, pests, and weeds. The guidelines also address two land-use issues: public access and roads, and conversion to non-forest use. The manual provides a clear definition of each element targeted for conservation, provides a rationale for its importance to biodiversity, and presents recommended practices. Both versions of Maine's biodiversity guidelines (Flatebo *et al.* 1999, Elliot 2008) generally focus on what is being retained in the forest after a harvest, so they are as applicable to woody biomass harvesting as they are to traditional round wood operations.

All timber harvesting can affect wildlife habitat, but the key concern is whether impacts are significant at the landscape level and biological indicators are important tools for measuring forest biodiversity in this regard. Hagan and Whitman (2006) point out however, that although science can direct selection of biological indicators, it is still weak in selecting specific target levels. Elliot (2008) also describes significant challenges to setting specific targets at the site-level. For this region, stand-level targets for forest structure have been established based on expert opinion. For example, Elliot (2008) recommends retaining *"a minimum of four secure cavity trees or snags per acre, with one exceeding 24 inches dbh and three exceeding 18 inches dbh"*. Specific size classes for downed logs are also suggested to be *"greater than 12 inches dbh and greater than 6 feet in length"*. These, and other regional targets, are qualified by statements indicating it is not always possible or appropriate to manage the habitat requirements for all species in all areas at the same time and that some management practices can conflict with each other. Stand-level application of those guidelines is left to the forest practitioner. Since there is not widespread acceptance of those guidelines within Maine's forest industry, specific targets for maintenance of site-level biodiversity were not included in Maine's biomass guidelines.

Implementation

A deliberate effort was made to avoid prescriptive language as the guidelines were developed, so the challenge now becomes how to implement the guidelines. Even though detailed retention targets of a certain number of stems per acre would have been easier to implement and audit, scientific evidence is lacking in that regard. Forest practitioners (including loggers and landowners) must find different ways to implement the concepts addressed in the guidelines during harvest operations. The key to this approach is planning. They must develop a pre-harvest plan that considers critical elements related to retention of woody biomass. Plans may include avoiding biomass removals on some portions of the harvest block, retention of critical habitat areas identified by cavity trees, creation of downed wood during harvest activities, and use of brush in trails for erosion prone locations. These issues must be handled on a site by site basis.

Several organizations in Maine are incorporating the guidelines into existing training and education programs for loggers, family forest owners, and foresters. Some of these groups include: the State Implementation Committee for SFI, the Maine Forest Service, the Certified Logging Professional Program, Master Logger Certification Program, and the Small Woodland Owners Association of Maine.

Conclusions

The recently developed woody biomass retention guidelines for Maine summarize key issues related to soil productivity, water quality and forest biodiversity in the context of an existing biomass industry. Maine is fortunate to have long-term soil studies, successful BMPs for water quality, and extensive research on forest biodiversity. Even with all of that information, it is still left to the forest practitioner to make site-level decisions and these guidelines serve as reminders for what is important in that regard with respect to woody biomass.

Acknowledgements

This work was a collaborative effort between the Maine Forest Service, the University of Maine, and the Trust to Conserve Northeast Forestlands. Funding was received from the Natural Resources Conservation Service, Maine Forest Service, the Maine Outdoor Heritage Fund (MOHF Grant No. 072-01-016), and the University of Maine's Forest Bioproducts Research Initiative (NSF Grant No. EPS-0554545).

References

Benjamin, J.G. 2009. *Maine's logging industry: Developing a health assessment.* Presented at the New England Regional Council on Forest Engineering workshop on March 9, 2009. The University of Maine, Orono Maine.

Benjamin, J., R.J. Lilieholm, and D. Damery. 2009. *Challenges and opportunities for the Northeastern Forest Bioindustry.* Journal of Forestry. 107(3): 125-131.

Dunk, J.R. and J.J.V.C. Hawley. 2009. *Red-tree vole habitat suitability modeling: Implications for conservation and management.* Forest Ecology and Management. (In Press.)

Elliot, CA. (Editor) 2008. *Biodiversity in the Forests of Maine: Guidelines for Land Management (2008 Edition).* University of Maine Cooperative Extension Bulleting 7174. Orono, M.E. 166 pp.

Flatebo, G., C.R. Foss, and S.K. Pelletier. 1999. *Biodiversity in the Forests of Maine: Guidelines for Land Management.* University of Maine Cooperative Extension. Orono, M.E. 167 pp.

Hagan, J.M. and R.B. Boone. 1997. *Harvest Rate, Harvest Configuration, and Forest Fragmentation: A simulation of the 1989 Maine Forest Practices Act.* Manomet Center for Conservation Sciences, Manomet, MA. Pp17.

Hagan, J.M. and A.A. Whitman. 2006. *Biodiversity indicators for sustainable forestry: simplifying complexity.* Journal of Forestry. 104(4): 203-210.

Hansen, A.J., T.A. Spies, F.J. Swanson, and J.L. Ohmann. 1991. *Conserving biodiversity in managed forests lessons from natural forests.* Bioscience. 41(6): 382-392.

Hornbeck, J.W., C.T. Smith, C.W. Martin, L.M. Trittion, and R.S. Pierce. 1990. *Effects of Intensive Harvesting on Nutrient Capitals of Three Forest Types in New England.* Forest Ecology and Management. 30:55-64.

Kahl, S. 1996. *A Review of the Effects of Forest Practices on Water Quality in Maine.* A report to the Maine Department of Environmental Protection – Bureau of Land and Water Control. 52p.

Likens, G.E., F.H. Bormann, N.W. Johnson, D.W. Fisher, and R.S. Pierce. 1970. *Effects of Cutting and Herbicide Treatment on Nutrient Budgets in the Hubbard Brook Watershed-Ecosystem.* Ecological Monographs. 40:23-47.

Maine Forest Service. 2004. *Best Management Practices for Forestry: Protecting Maine's Water Quality.* 93 pp.

Maine Forest Service. 2009. Annual publications. http://www.maine.gov/doc/mfs/pubs/annpubs.htm.

Marciano, J.A., R.J. Lilieholm, J.E. Leahy, and TL. Porter. 2009. *Preliminary Findings of the Maine Forest and Forest Products Survey.* A Report to the Forest Bioproducts Research Initiative. University of Maine. Orono, ME. 54p.

Putz, F.E., G.M. Blate, K.H. Redford, R. Fimbel, and J. Robinson. 2001. *Tropical forest management and conservation of biodiversity: An overview.* Conservation Biology. 15(1):7-20.

Roberge, J.M., P. Angelstam, and M.A. Villard. 2008. *Specialised woodpeckers and naturalness in hemiboreal forests – Deriving quantitative targets for conservation planning.* Biological Conservation. 141:997-1012.

Shepard, J.P. 2006. *Water quality protection in bioenergy production: The US system of forestry Best Management Practices.* Biomass and Bioenergy 30: 378-384.

Smith, C.T. Jr., M.L. McCormack Jr., J.W. Hornbeck, and C.W. Martin. 1986. *Nutrient Removal from a Red Spruce-Balsam Fir Whole-tree Harvest.* Canadian Journal of Forest Research. 16:381-388.

Stafford, C., M. Leathers, and R. Briggs. 1996. *Forestry-Related Nonpoint Source Pollution in Maine: A Literature Review.* CFRU Information Report 38. University of Maine, Orono, Maine. Pp 18.

Whitman, A.A. and J.M. Hagan. 2007. *An index to identify late-successional forest in temperate and boreal zones.* Forest Ecology and Management. 246:144-154.

Vaillancourt, M.A., P. Drapeau, S. Gauthier, and M. Robert. 2008. *Availability of standing trees for large cavity-nesting birds in the eastern boreal forest of Quebec, Canada.* 255:2272-2285.

Young, H.E. and P.M. Carpenter. 1976. *Weight, Nutrient Element and Productivity Studies of Seedlings and Saplings of Eight Tree Species in Natural Ecosystems.* Maine Agic. Experiment Station Technical Bulletin 28. University of Maine, Orono, ME.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Appendix A

List of Woody Biomass Retention Guidelines for Maine

General Recommendations

Develop a site-specific harvest plan that addresses the forest values identified in this brochure. Publications and programs, such as the Water Quality BMPs, Master Logger Harvest Integrity System, and the Certified Logging Professional Program, can provide general pre-harvest planning guidance. Contact your local MFS District Forester for on-the-ground assistance. Call 1-800-367-0223, or visit www.maineforestservice.gov, for more information.

• Follow all applicable regulations and Water Quality BMPs.

• Strive to optimize utilization and value of all products removed from each site. For example, it is worth considering whether tops, limbs or other woody material has greater value on a trail to prevent erosion or on the landing as biomass chips.

Soil Productivity

Except where scarification of the soil is important for regeneration, leave the litter layer, stumps, and roots as intact as possible. Wood decaying on the ground, especially tops and limbs, contributes nutrients that help build up the growth potential of the soil.

• Leave as many tops and branches as possible on: low-fertility sites, shallow-to-bedrock soils, coarse sandy soils, poorly drained soils, steep slopes, and other erosion-prone sites.

Water Quality

The Water Quality BMP manual describes many fundamental approaches to protect water quality on harvest operations. These include anticipating site conditions, controlling water flow, and stabilizing exposed soil.

• In particular the Water Quality BMP manual highlights that:
   – disturbance of the forest floor should be minimized;

– woody biomass may be used to control water flow, to prevent soil disturbance, and/or to stabilize exposed mineral soil, especially on trails and the approaches to stream crossings; and
– woody biomass used for erosion control and soil stabilization may be left in place,
if it is above the normal high water mark of streams or other water bodies.

Forest Structure

Wood of all sizes provides a range of habitats for other organisms that are essential to a fully productive forest.

• **Leave as much dead wood on site as possible.**
– Leave as many snags standing as safety and access will permit.
– Leave any felled snags in place.
– Limit disturbance to existing down logs.
– If large woody material is lacking on the ground, consider leaving some newly-cut logs scattered throughout the harvest area.
– Large woody material can be created over time by retaining all snags possible and leaving some large trees to die.

• **Leave some live wildlife trees.**
– Retain live cavity trees on site. Cavity trees are live trees with holes, open seams or hollow sections that wildlife can use.
– Leave live trees with rot when cavity trees are not available.

• **Leave some mast producing trees.**
– Species such as oak, beech, apple, black cherry, pin cherry, hickory, and raspberry produce valuable food for many wildlife species.

• **Vary the amount of snags, down logs, and wildlife trees across the harvest area.**
– Stream buffers, retention patches and other protection zones provide an opportunity to leave more large trees than may be possible in other harvest areas.
– Leaving lightly cut or un-cut patches in heavy harvest areas yields more biodiversity benefits than widely dispersed single trees.
– The larger the retained patch, the greater the benefit to sensitive understory species.

• **Leave as much fine woody material as possible.**
– Where possible and practical (depending on harvest method and system) retain and scatter tops and branches (fine woody material) across the harvest area.

– If trees are delimbed at roadside, haul a portion of the tops and limbs back into the woods. Leave the material along skid trails if carrying it off the trail would cause greater damage.

GPS and GIS Analysis of Mobile Harvesting Equipment and Sediment Delivery to Streams During Forest Harvest Operations on Steep Terrain

Daniel Bowker, Jeff Stringer, Chris Barton, Songlin Fei[1]

ABSTRACT.—Sediment mobilized by forest harvest machine traffic is a major contributor to the degradation of headwater stream systems. This study monitored forest harvest machine traffic in order to analyze how this traffic affects sediment delivery to stream channels. Harvest machines were outfitted with global positioning system (GPS) dataloggers, recording machine movements and working status. Sediment delivery to streams was monitored by scouting for overland sediment delivery paths after the completion of harvest operations. Each sediment path was categorized as to source, width of path where it enters the stream, slope degree and distance to sediment source, ground disturbance level at source, trail morphology at sediment source, and whether a water control structure contributed to sediment delivery. The harvest was completed using two replications each of three combinations of streamside buffer width and canopy retention level, and two unharvested controls. GPS positional data from the mobile harvesting equipment, along with the sediment delivery information, was analyzed in a geographic information system (GIS) in order to draw conclusions about the influences of buffer width, canopy retention level, and traffic intensity on delivery of sediment to headwater streams. Results indicate that increased forested buffer width correlates with reduced sediment delivery to stream channels.

INTRODUCTION

The negative effects of timber harvesting on streams and riparian habitat are well-documented. Forest operations in and around riparian areas can cause increased nutrient delivery to streams, as well as increases in water temperature and stream sediment levels (LeDoux and Wilkerson 2006; Rashin et al. 2006; Arthur, Coltharp, and Brown 1998; Binkley and Brown 1993; Kochenderfer and Edwards 1990; Corbett, Lynch, and Sopper 1978). Elevated nutrient levels can cause eutrophication, increasing biological activity and reducing the amount of dissolved oxygen available for aquatic life, while the export of nutrients from harvested areas can decrease long-term site productivity (Corbett, Lynch, and Sopper 1978). Increased stream temperature can also reduce the amount of oxygen available for aquatic life (Corbett, Lynch, and Sopper 1978). Sediment can suffocate fish and aquatic invertebrates, and when deposited on the streambed can reduce spawning habitat (Corbett, Lynch, and Sopper 1978). In the process, increased stream sedimentation can cause a reduction in the biodiversity and biomass in aquatic systems (Summer et al. 2006).

In 1972, the Federal Water Pollution Control Act and its related amendments directed the states to develop Best Management Practices (BMPs) to address

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these non-point source pollution (NPSP) impacts of forest operations. Of the various NPS pollutants, sediment is commonly seen as the most important type in forested areas (Miller and Everett 1975). Most states’ BMPs include Streamside Management Zone (SMZ) recommendations or regulations in which a buffer strip is left undisturbed or minimally disturbed. This buffer strip is intended to filter sediment and nutrients as they travel through the SMZ, as well as reduce the effect of canopy removal on stream temperature (Blinn and Kilgore 2001; Stringer and Perkins 2001; Stringer and Thompson 2000; Stringer et al. 1998). SMZs have been shown to be generally effective at reducing nutrient inputs, temperature increases, and sediment levels (Lakel et al. 2006; LeDoux and Wilkerson 2006; Rashin et al. 2006; Summer et al. 2006; Aust and Blinn 2004; Wynn et al. 2000; Arthur, Coltharp, and Brown 1998; Kochenderfer, Edwards, and Wood 1997; Martin and Hornbeck 1994; Binkley and Brown 1993; Grayson et al. 1993; Kochenderfer and Edwards 1990; Corbett, Lynch, and Sopper 1978; Trimble and Sartz 1957).

Most sediment delivered to streams during forest operations involves road, trail, and landing construction and use (Croke and Hairsine 2006; Rashin et al. 2006; Stuart and Edwards 2006; Benda et al. 2005; Germain and Munsell 2005; Aust and Blinn 2004; Hairsine et al. 2002; Kreutzweiser and Capell 2001; Swank, Vose, and Elliott 2001; Ketcheson, Megahan, and King 1999; Arthur, Coltharp, and Brown 1998; Kochenderfer, Edwards, and Wood 1997; Martin and Hornbeck 1994; Grayson et al. 1993; Stuart and Carr 1991; Kochenderfer and Edwards 1990; Swift 1988; Corbett, Lynch, and Sopper 1978; Trimble and Sartz 1957). Many states’ SMZ regulations, including Kentucky’s, attempt to mitigate the effects of the transportation network by requiring roads, trails, and landings to be located outside the SMZ (Blinn and Kilgore 2001; Stringer and Perkins 2001; Stringer and Thompson 2000; Stringer et al. 1998).

In Kentucky, SMZs on perennial streams (those streams that normally flow year-round) must be 25’ wide on ground sloping less than 15% from the streambank, and 55’ wide on ground sloping more than 15% from the streambank; no roads, trails, landings, or harvest machine use should occur in this zone, and 50% of the canopy trees must be retained (Stringer and Perkins 2001; Stringer et al. 1998). For Kentucky intermittent streams (those streams that flow during the wetter periods of the year), a 25’ buffer is required for roads, trails, landings, and harvest machine use regardless of slope; all trees may be removed from this buffer (Stringer and Perkins 2001; Stringer et al. 1998). Ephemeral streams in Kentucky (those channels where water flows during storm events or snowmelt) receive no SMZ buffer zone protection for transportation network location, equipment operation, or canopy retention (Stringer and Perkins 2001; Stringer et al. 1998). Other states’ SMZ regulations differ markedly, and some states’ SMZs are voluntary (Blinn and Kilgore 2001; Stringer and Thompson 2000).

Many states’ SMZ regulations or recommendations stem from research done in the White Mountains of New Hampshire in the 1950’s, with regional variations based upon differences in geology, soils, and harvesting systems (Trimble and Sartz 1957). However, little research has been done to tailor these recommendations to specific regions or sites, and very few studies have looked into the efficacy of different buffer widths and canopy retention levels (Lakel et al. 2006; Rashin et al. 2006; Aust and Blinn 2004; Blinn and Kilgore 2001; Arthur, Coltharp, and Brown 1998; Corner, Bassman, and Moore 1996). In fact, the lack of region and site specific information about SMZ buffers is partly responsible for the wide variations in SMZ regulations and recommendations among states (Stringer and Thompson 2000). Most research that has been done on BMPs and SMZs has been directed at larger order streams; smaller order, or headwater, streams are more difficult to access and study, and have less fish habitat (Rashin et al. 2006; Benda et al. 2005). Headwater streams, however, can comprise 60-80% of the drainage network, and headwater stream impacts during forest operations have much to do with effects on larger streams (Benda et al. 2005). There is a need for research into the mechanisms delivering sediment to small streams (Aust and Blinn 2004; Arthur, Coltharp, and Brown 1998), and specifically how forest harvesting machinery and its associated transportation network deliver this sediment (Kreutzweiser and Capell 2001).

GPS tracking of forest machine movements has recently shown promise in obtaining detailed information on harvest machine use of the forest transportation network and how this use is related to environmental variables (Michels 2009; Davis and Kellogg 2005; McDonald, Carter, and Taylor 2002; Taylor et al. 2001; Veal et al. 2001; Carter, McDonald, and Torbert 1999). GPS accuracies under heavy forest canopy can cause some reliability problems with the data (Deckert and Bolstad 1999); however, data reliability is sufficient to produce workable maps of harvest machine traffic patterns (McDonald, Carter, and Taylor 2002; Veal et al. 2001; Carter, McDonald, and Torbert 1999). The positional information gathered can produce maps showing areas of different traffic intensities (Michels 2009; Davis and Kellogg 2005; McDonald, Carter, and Taylor 2002; Taylor et al. 2001; Veal et al. 2001; Carter, McDonald, and Torbert 1999). These maps can be analyzed with sediment delivery data to show how different traffic intensities and control points such as stream crossings contribute to the sedimentation of harvest area streams. This information should lead to better transportation network planning and design, in order to minimize the delivery of sediment to streams during forest operations.

The objective of the present study was to begin this process of testing and refining SMZ variables. In particular, the intensity of forest harvest machine traffic in areas near SMZs was quantified in order to determine if traffic intensity had an effect on the number and relative magnitude of overland sediment flows into and through the SMZ. Various configurations of SMZ buffer width and canopy retention percentage were tested along with differing traffic intensities to establish if SMZ configuration had a significant effect on reducing the potential for overland sediment delivery to streams.

STUDY SITE

This study took place from June 2008 through October 2009 on the University of Kentucky’s Robinson Forest, a 15,000 acre experimental forest located in Breathitt, Knott, and Perry Counties in eastern Kentucky. The forest is in the rugged eastern area of the Cumberland Plateau (longitude -83.14 degrees west, latitude 37.47 degrees north), and is composed of mixed mesophytic and oak-hickory forest types (Overstreet 1984). The forest was entirely harvested from 1908-1923 by the Mowbray and Robinson Lumber Company, and has since grown into an 80-100 year old even-aged forest, with only scattered active management in the past several decades.

This section of the Cumberland Plateau is characterized by deep valleys, steep valley walls, and long narrow ridges; elevations in Robinson Forest range from 800 to 1600 feet above mean sea level (Overstreet 1984). Geology consists of interbedded sandstone, siltstone, shale, and coal, while soils in the Shelly Rock Fork study area (where this research was conducted) are classified into three main groups: the Cloverlick-Shelocta-Cutshin complex, the Dekalb-Marrowbone-Latham complex, and the Shelocta-Gilpin-Hazleton complex (U.S. Department of Agriculture 2009). The Cloverlick-Shelocta-Cutshin complex is a deep, well-drained silt loam found on shaded slopes; the Dekalb-Marrowbone-Latham complex is shallow to moderately deep, well-drained, rocky or stony, silty clay to loam on the upper third of steep hillsides; and the Shelocta-Gilpin-Hazleton complex is a shallow to moderately deep, well-drained, rocky or stony, silty clay to loam associated with warm side slopes (U.S. Department of Agriculture 2009). All three soil complexes in the Shelly Rock Fork study area are classified as severely erodible both on and off roads and trails, and as poorly suited for roads (U.S. Department of Agriculture 2009). As such, the three soil complexes comprising the study area will be treated as essentially similar for the purpose of this study.

METHODS

The study detailed in this paper is one part of a larger research undertaking concerning headwater stream quality. This larger undertaking, the Robinson Forest Streamside Management Zone project (hereafter SMZ project), is a paired watershed study with replications (Arthur, Coltharp, and Brown 1998). In a paired watershed study, two watersheds of similar size, topography, soils, and hydrology are chosen. Water quality parameters at the outlets of these two watersheds are then monitored for a period of time to verify that they do behave with hydrologic similarity. Once this similarity is established, a treatment is implemented on one watershed, leaving the other as an untreated control. Because of the pretreatment calibration, water quality changes in the treated watershed can be attributed to the treatment itself, rather than to confounding factors.

The SMZ project involved commercial timber harvest on six unit boundaries, with two unharvested controls. The six boundaries comprised two replications each of three different SMZ configurations of buffer strip width and canopy retention level. Due to the lack of a full suite of available GPS equipment for this study, only three of the six SMZ project harvest boundaries were incorporated into this study, one each using the three different SMZ configurations.

Table 1 details the treatment configurations used. Boundary 1 had a 55′ harvesting equipment buffer on the perennial stream section with canopy retention of 50%, a 25′ buffer on the intermittent stream section with no canopy retention, and no buffer on the ephemeral channels with no canopy retention. Boundary 2 had 110′ buffers on the perennial stream sections with 100% canopy retention, 50′ buffers on the intermittent stream sections with 25% canopy retention, and 25′ buffers on the ephemeral channels with retention of channel bank trees. Boundary 3 had a 55′ buffer on the perennial stream section with 100% canopy retention, a 25′ buffer on the intermittent stream section with 25% canopy retention, and no buffers on the ephemeral channels but with retention of the channel bank trees.

Before the initiation of forest harvest, MultiDAT Jr. GPS receivers (Castonguay Electronique, Longueuil, Quebec, Canada) were installed on all mobile harvesting equipment. The suite of equipment used by the logging contractor included a rubber-tired grapple skidder (Caterpillar 545); a rubber-tired cable skidder (Caterpillar 525); three bulldozers (John Deere 650, 700, and 850); a Timbco 445EXL tracked swing-arm feller-buncher; and two Barko knuckleboom loaders (160 and 255). Loaders were equipped with MultiDAT units, but did not take GPS positions, as the machines were stationary at the landing. All MultiDATs were set to take a GPS position every 30 seconds. MultiDAT data was retrieved using an iPAQ Pocket PC (Hewlett-Packard Company, Palo Alto, CA), and downloaded into MultiDAT version 5.1.3 software. GPS positions were exported using the MultiDAT software into the ArcGIS (ESRI, Redlands, CA) shapefile format for analysis with version 9.2 of ArcGIS.

After completion of the harvest, all perennial, intermittent, and ephemeral stream sections were scouted for overland sediment paths. Each of these paths was characterized by several variables: width where it enters the stream, slope distance to source, slope degree, source type (primary, secondary, or tertiary skid trail; haul road; general harvest area; natural wash; natural slip), skid trail morphology at source (degree of slope if sloping, level trail, low point of trail), water control structure influence (whether a waterbar, dip, or berm cut was present at the source of the sediment path and contributing to sediment flow), and whether the sediment path entered the stream from the right or left looking upstream. Sediment paths were GPS located if possible, using a Trimble GeoXM handheld GPS unit (Trimble Navigation Limited, Sunnyvale, CA). If signal strength was not sufficient to obtain a GPS fix, sediment paths were plotted on the GeoXM based on pacing from the last GPS fix. Only those sediment paths that could be traced to documented as caused by harvest activity and machine movement were used for this study (i.e. natural washes and natural slips were not used).

Experimental units subjected to statistical analysis for this study were roughly rectangular plots of sloping land area bordering stream segments. Figure 1 shows the eleven units analyzed for harvest boundary 3, while figure 2 is a closeup of an analysis unit in boundary 3 along the lower perennial section of stream. Each unit encompasses a section of perennial, intermittent, or ephemeral stream, the ground slope directly above this section of stream, and the segments of the skid trail network directly upslope from the stream section. All units were drawn to encompass at least one section of primary skid trail in order to ensure that each unit had enough machine traffic to make it worth entering into the analysis. Ephemeral drainages entering the main stream channel on the perpendicular were avoided when creating the units, as the sediment delivery in these is of a different nature, and will be analyzed in another related study. Natural landscape breaks were used in creating the analysis units (i.e. spots where ephemeral channels entered on the perpendicular, locations where the stream type changed, etc.). Units were created so as to encompass the slope area above the section of primary skid trail to a line midway between that trail and the primary trail directly upslope. This included GPS positions that were plotted above the skid trail of interest due to GPS positional error, effectively assigning the inter-trail GPS positions to the trail they most likely actually occurred on.

For each experimental unit, average slope value and maximum slope value were derived from 10 meter digital elevation model (DEM) data. Average aspect for each unit, derived from the 10 meter DEM, was transformed to a moisture index from 0 to 2, with 0 representing the driest slopes (southwest exposure) and 2 representing the wettest slopes (northeast exposure), following Beers, Dress, and Wensel (1966). An index value of machine traffic intensity was calculated by counting the number of GPS positions present within the analysis unit border, and dividing this by the area of the unit in acres. A skid trail density index value was calculated by measuring the total feet of skid trail within the analysis unit, and dividing by the area of the unit in acres. The minimum distance from a skid trail within the unit to its associated stream section was derived using the measure tool in ArcGIS. The total number of sediment paths arising within the unit and entering the associated stream section was determined with the sediment path GPS data. The total width of sediment paths entering the stream section within the unit was also determined from the sediment path GPS data, as well as an average sediment path width within each analysis unit. The proportion of sediment paths associated with a water control structure was derived for each unit with at least one sediment path.

Data was analyzed with the GLM procedure of the SAS statistical software package (SAS Institute Inc., Cary, NC). Response variables were the total number of sediment paths within an analysis unit, total width of all sediment paths within an analysis unit, and average width of all sediment paths within an analysis unit. Independent variables entered into the model included buffer width, canopy retention percentage, traffic intensity index, maximum slope of the analysis unit, minimum distance from trail to stream within the analysis unit, trail density index within the analysis unit, and the moisture index average for the analysis unit. All independent variables were entered as quantitative variables. As the 50 foot and the 55 foot buffer widths were operationally equivalent, only 4 levels of buffer width were entered into the model: 0, 25, 55, and 110 feet. Five levels of canopy retention percentage were entered into the model: 0, 10, 25, 50, 100. The 10% value is an approximate canopy retention value for the retention of the channel bank trees along the ephemeral channels in harvest boundaries 2 and 3 (table 1).

RESULTS

Forty-one analysis units were identified and mapped: 8 in boundary one, 22 in boundary two, and 11 in boundary three. Twenty-two analysis units had no sediment paths, while 19 units had at least 1. Table 2 presents summary statistics for selected attributes of all analysis units. The mean number of sediment paths for all analysis units combined was 1.2 paths (standard error [SE] 0.3 paths). The mean number of sediment paths for the 19 units with at least 1 present was 2.5 paths (SE 0.3 paths). Mean total width of sediment paths for the 19 analysis units with at least 1 present was 19.4 feet (SE 3.2 feet). Mean average sediment path width for the 19 units with at least 1 present was 7.6 feet (SE 1.1 feet).

Three linear models including all dependent and independent variables mentioned above were produced (table 3). Model 1, with total number of sediment paths as the response variable, was significant ($p=.0152$), with an R-squared value of 0.39. Within the model, 3 independent variables had a significant influence on the total number of sediment paths: moisture index ($p=0.0164$), buffer width ($p=0.0443$), and canopy retention percentage ($p=0.0109$). The other independent variables (traffic intensity index, maximum slope, minimum distance from trail to stream, and skid trail density index) were not significant at $\alpha=0.1$. Moisture index was positively correlated with total number of sediment paths, which was expected. Buffer width was negatively correlated with total number of sediment paths, also expected. However, canopy retention percentage was positively correlated with total number of sediment paths, an unexpected result.

Model 2, with total width of sediment paths as the response variable, was also significant ($p=0.0042$), with an R-squared value of 0.44. Within the model, 5 independent variables had a significant influence on the total width of sediment paths: buffer width ($p=0.0092$), canopy retention percentage ($p=0.0027$), traffic intensity index ($p=0.0442$), minimum distance from trail to stream ($p=0.0280$), and moisture index ($p=0.0053$). The other independent variables (maximum slope and skid trail density index) were not significant at $\alpha=0.1$. Buffer width was negatively correlated with total width of sediment paths, expected as above. Canopy retention percentage was positively correlated with total width of sediment paths, unexpected as above. Traffic intensity index was negatively correlated with total width of sediment paths, which is also an unexpected result. The minimum distance from trail to stream was negatively correlated, which was expected. Moisture index was positively correlated with total width of sediment paths, again expected.

Model 3, with average width of sediment paths as the response variable, was also significant ($p=0.0037$), with an R-squared value of 0.45. Again, 5 independent variables had a significant influence on the average width of sediment paths: buffer width ($p=0.0057$), canopy retention percent ($p=0.0109$), traffic intensity index ($p=0.0076$), minimum distance from trail to stream ($p=0.0092$), and moisture index ($p=0.0038$). The other independent variables (maximum slope and skid trail density index) were not significant at $\alpha=0.1$. Correlation of all 5 significant variables with the average width of sediment paths was the same as the previous model reported.

Of all the sediment paths discovered and analyzed, each and every one was associated with a water control structure of some kind at the source of the path (waterbar, dip, or berm cut).

DISCUSSION

All 3 linear models showed distinct similarities, as buffer width, canopy retention percentage, and moisture index had a significant influence on overland sediment delivery paths in all of them. In models 2 and 3, these 3 variables were joined in significance by traffic intensity index and minimum distance from trail to stream.

The negative correlation of buffer width with sediment path presence is an expected result, as field observation shows that with increasing forested buffer width, fewer sediment paths actually reach the stream, but instead are dispersed across the forest floor before entering. This has important implications for SMZ regulations, as sediment can be kept from entering waterways by increasing SMZ buffer width.

The positive correlation of canopy retention percentage with sediment path presence is unexpected, as theory would tell us that with greater total leaf area in the SMZ, more evapotranspiration would occur, thereby decreasing soil moisture and making it less likely that the soil would saturate to the point of running off downhill in a sediment path. One possible explanation is that there may be microsite differences among analysis units contributing to greater numbers and widths of sediment paths, such as subsurface channels in the soil. Also, much of the problem here is confounding by the interaction of buffer width and canopy retention percentage. For example, boundary 2 had 4 analysis units with 100% canopy retention percentage and a 110 foot wide buffer strip, and a total of 1 sediment path in those 4 units combined; while boundary 3 also had 4 analysis units with 100% canopy retention percentage, but had a narrower 55 foot buffer strip, and a total of 14 sediment paths in those 4 units combined. As buffer width has already been shown to be a significant factor in reducing the number and width of sediment paths, this is evidence that greater canopy retention percentage cannot overcome the disadvantage of a narrower buffer strip.

Aspect seems to be a noteworthy contributor to the potential for overland erosion pathways, as the moisture index derived from aspect was significantly positively correlated with sediment path occurrence in all 3 models. This is to be expected, as greater moisture in the soil solution should lead to the enhanced ability of that solution to escape downhill.

Traffic intensity index was significantly negatively correlated with sediment path occurrence in models 2 and 3, which is somewhat surprising. One would assume that more concentrated harvest machine traffic would increase the likelihood that sediment flows would reach the stream. However, it is possible that most of the potential for overland sediment flow is created when skid trails are built, and that subsequent trafficking on them does not increase sediment movement appreciably. Arguably, increased trafficking over the same trails may actually decrease overland sediment flow potential by compacting the soil, as compared to less trafficked trails with less compacted soil.

The minimum distance from trail to stream was significantly negatively correlated with sediment path occurrence in models 2 and 3, which makes intuitive sense. As the distance from trail to stream grows, the potential for overland sediment flows to reach the stream decreases, as the flow has more distance to spread across the forest floor and disperse, losing energy as it encounters the roughness of the forest floor surface and the litter layer and slash on the ground.

CONCLUSIONS

This study used GPS technology to track the movements of harvest machines during a commercial forest harvest, and analyzed the overland sediment flow response. The commercially available MultiDAT Jr. GPS units used to track the machines were quite effective and produced workable maps of machine movements from which traffic intensity could reliably be determined. However, traffic intensity was either not a significant factor or was negatively correlated with overland sediment flow potential, and by extension with sediment levels in the headwater streams evaluated. The most plausible explanation for this state of affairs is that the potential for sediment delivery to streams is created as the trails are put in and soil gets spilled over the embankment, and that this potential does not increase with the number of passes over the same area. Operationally, this means that a well-designed skid trail system should be effective at preventing sediment delivery to streams regardless of the number of passes over the same area. Therefore, it is not necessary to encourage operators to build more trail in order to limit the number of passes over areas near SMZs.

Canopy retention percentage was unexpectedly positively correlated with sediment delivery (i.e. the more canopy that was retained in this study, the greater the number and relative magnitude of sediment delivery events), and therefore meaningful conclusions are tough to reach about this attribute based on the results of this study. Certainly this does not recommend leaving less canopy in streamside buffers in order to reduce sediment delivery potential. There seem to be confounding factors in this study, like the interaction of buffer width and canopy retention percentage, that affected the results. However, given the evidence that increasing buffer width prevents overland sediment delivery, a sensible recommendation would be to keep the minimum canopy retention percentages in place. That way, less equipment traffic would occur near the SMZ than would happen if the entire SMZ canopy were harvested. In many cases in this terrain, the lowest portion of the stream valley is so steep that little decent timber occurs there anyway, so that recommending an increase in canopy retention percentage in these very steep areas may further decrease equipment traffic near the SMZ and hence the potential for overland sediment delivery, while not preventing too much valuable timber from being harvested from the SMZ.

The most operationally important factors, supported by the present study, are the attributes of SMZ buffer width and aspect of harvested area. As buffer width was significantly negatively correlated with sediment delivery in all three models, it is clear that increasing the width of the SMZ buffer reduces the potential for overland delivery of sediment. This has important implications for SMZ recommendations concerning harvest operations near headwater streams in steep terrain, as it is necessary for the prevention of stream sedimentation to ensure that an adequately wide buffer strip is installed. The importance of aspect qualifies this recommendation, however. Given that aspect was significant in all three models, so that increased soil moisture leads to greater potential for sediment delivery, it could be argued that wider buffers are needed in areas with more northerly and easterly aspects, and that narrower buffers would suffice in areas facing more south and west. Instead of SMZ buffer prescriptions that require or recommend the same buffer width regardless of harvest area topography, more nuanced prescriptions based on local conditions may be more effective in preventing stream sedimentation, while also allowing the fullest utilization of the timber resource that exists near the SMZ.

Table 1.—Treatments used for Robinson Forest Streamside Management Zone project.

Boundary	Stream type	SMZ Width	Canopy Cover Retained
	perennial		
0	intermittent	control; no treatment	
	ephemeral		
	perennial	normal (55’)	normal (50%)
1	intermittent	normal (25’)	normal (0%)
	ephemeral	normal ephemeral width (0’)[2]	normal (0%)
	perennial	2 x normal (110’)	2 x normal (100%)
2	intermittent	2 x normal (50’)	2 x normal (25%)
	ephemeral	normal intermittent width (25’)[1]	2 x normal (bank trees)
	perennial	normal (55’)	2 x normal (100%)
3	intermittent	normal (25’)	2 x normal (25%)
	ephemeral	normal ephemeral width (0’)[1]	2 x normal (bank trees)

[1]Improved stream crossings.
[2]No improved stream crossings.

Table 2.—Selected statistics describing the results of the sediment path survey in the three harvest boundaries.

Attribute	Mean	Standard error
Total number of sediment paths per analysis unit (all 41 units)	1.2	0.3
Total number of sediment paths per analysis unit (19 units with at least one sediment path)	2.5	0.3
Total width in feet of sediment paths per analysis unit (19 units with at least one sediment path)	19.4	3.2
Average width in feet of sediment paths per analysis unit (19 units with at least one sediment path)	7.6	1.1

Table 3.—Three linear models produced by the GLM procedure of the SAS statistical software package. Each model is listed with its response variable, the overall probability value for the model, the overall R^2 value for the model, and significant variables in the model with individual probability value and sign of correlation with model response variable.

Model	Response variable	Overall model p value	Overall model R^2 value	Significant variables with p value and correlation with response variable	
1	Total number of sediment paths per analysis unit	0.0152	0.39	Buffer width Canopy retention % Moisture index	0.0443 – 0.0109 + 0.0164 +
2	Total width of sediment paths per analysis unit	0.0042	0.44	Buffer width Canopy retention % Traffic intensity index Trail to stream distance Moisture index	0.0092 – 0.0027 + 0.0442 – 0.0280 – 0.0053 +
3	Average width of sediment path per analysis unit	0.0037	0.45	Buffer width Canopy retention % Traffic intensity index Trail to stream distance Moisture index	0.0057 – 0.0109 + 0.0076 – 0.0092 – 0.0038 +

Figure 1.—Map of harvest boundary 3 in green, showing units subjected to experimental analysis in orange. Perennial stream sections are in solid blue, intermittent sections are in dashed blue, and ephemeral stream channels are in hatched blue. The skid trail network is represented by black lines. The log landing area is at the high point at the northwest of the unit, and is represented in gray.

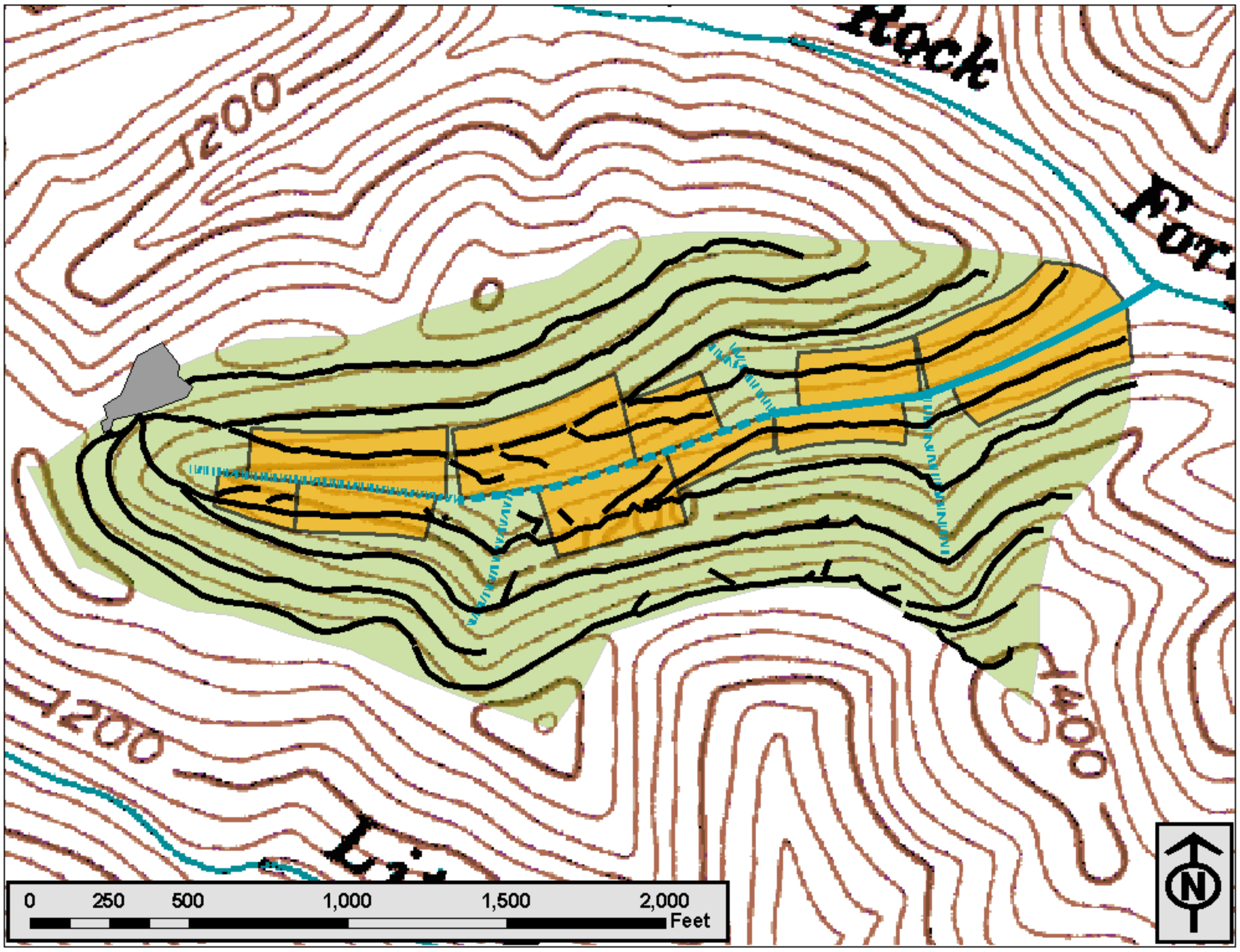
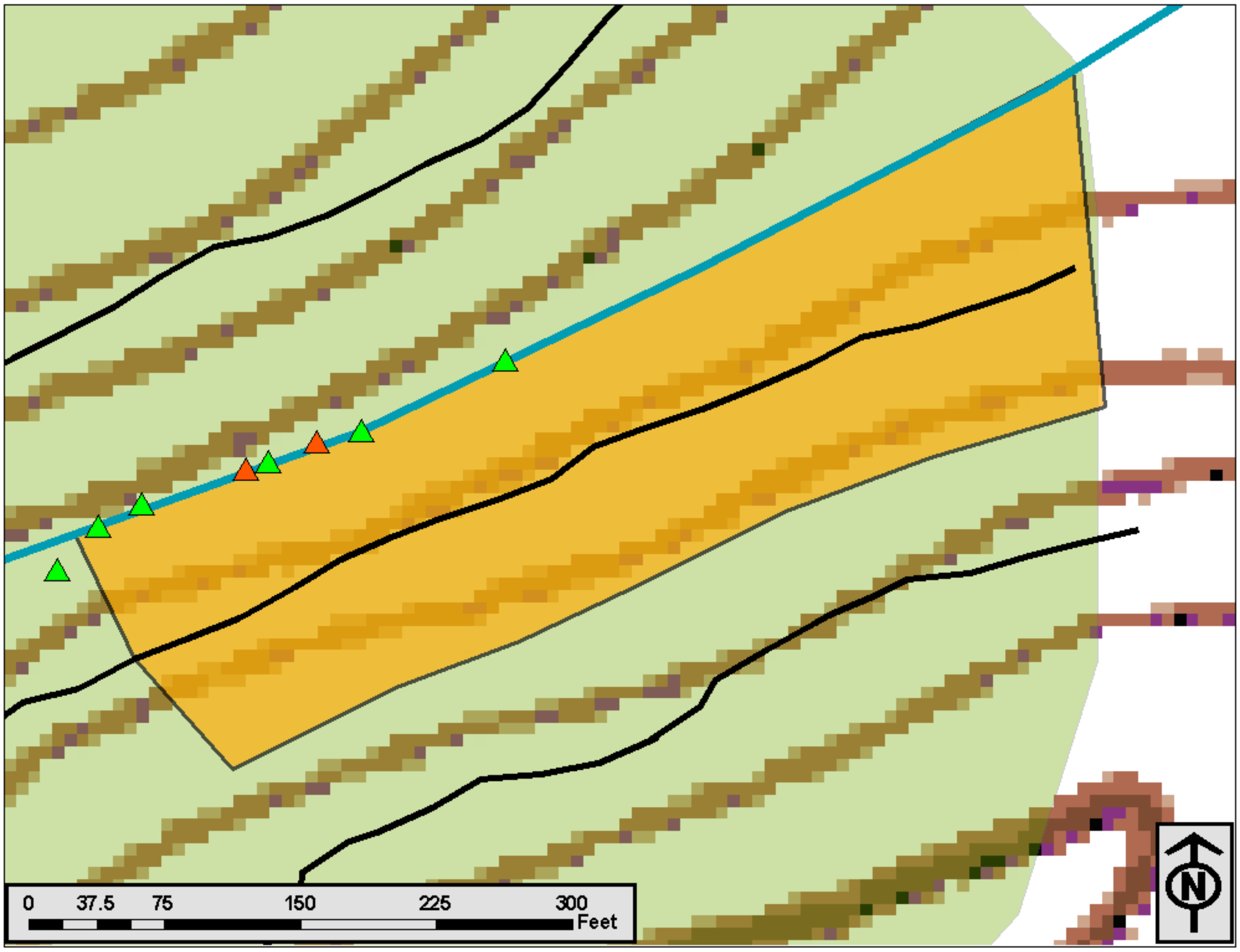


Figure 2.—Map of an analysis unit in boundary 3. Boundary 3 is in green, and the analysis unit is in orange. The section of perennial stream is in solid blue. The skid trail network is represented by black lines. Green triangles represent documented sediment paths coming into the stream from the south, while red triangles represent those coming in from the north.



LITERATURE CITED

Arthur, M. A., G. B. Coltharp, and D. L. Brown. 1998. Effects of best management practices on forest streamwater quality in eastern Kentucky. *Journal of the American Water Resources Association* 34 (3):481-495.

Aust, W. M., and C.R. Blinn. 2004. Forestry best management practices for timber harvesting and site preparation in the Eastern United States: an overview of water quality and productivity research during the past 20 years. *Water, Air, and Soil Pollution: Focus* 4:5-36.

Beers, T. W., P. E. Dress, and L. C. Wensel. 1966. Aspect transformation in site productivity research. *Journal of Forestry* 64 (10):691-692.

Benda, L., M. A. Hassan, M. Church, and C. L. May. 2005. Geomorphology of steepland headwaters: the transition from hillslopes to channels. *Journal of the American Water Resources Association* 41 (4):835-851.

Binkley, D., and T. C. Brown. 1993. Forest practices as nonpoint sources of pollution in North America. *Water Resources Bulletin* 29 (5):729-740.

Blinn, C.R., and M.A. Kilgore. 2001. Riparian management practices, a summary of state guidelines. *Journal of Forestry* 99 (8):11-17.

Carter, E.A., T.P. McDonald, and J.L. Torbert. 1999. Application of GPS technology to monitor traffic intensity and soil impacts in a forest harvest operation. In *Proceedings of the Tenth Biennial Southern Silvicultural Research Conference*. Shreveport, LA: USDA Forest Service Southern Research Station.

Corbett, E. S., J. A. Lynch, and W. E. Sopper. 1978. Timber harvesting practices and water quality in the eastern United States. *Journal of Forestry* 76 (8):484-488.

Corner, R. A., J. H. Bassman, and B. C. Moore. 1996. Monitoring timber harvest impacts on stream sedimentation: instream vs. upslope methods. *Western Journal of Applied Forestry* 11 (1):25-32.

Croke, J. C., and P. B. Hairsine. 2006. Sediment delivery in managed forests: a review. *Environmental Reviews* 14 (1):59-87.

Davis, C.T., and L.D. Kellogg. 2005. Measuring machine productivity with the MultiDat datalogger: a demonstration on three forest machines. In *Council on Forest Engineering Conference Proceedings*.

Deckert, C.J., and P.V. Bolstad. 1999. Global positioning system (GPS) accuracies in eastern U.S. deciduous and conifer forests. *Southern Journal of Applied Forestry* 20 (2):81-84.

Germain, R. H., and J. F. Munsell. 2005. How much land is needed for the harvest access system on nonindustrial private forestlands dominated by northern hardwoods? *Northern Journal of Applied Forestry* 22 (4):243-247.

Grayson, R. B., S. R. Haydon, M. D. A. Jayasuriya, and B. L. Finlayson. 1993. Water quality in mountain ash forests--separating the impacts of roads from those of logging operations. *Journal of Hydrology* 150 (2-4):459-480.

Hairsine, P. B., J. C. Croke, H. Mathews, P. Fogarty, and S. P. Mockler. 2002. Modelling plumes of overland flow from logging tracks. *Hydrological Processes* 16 (12):2311-2327.

Ketcheson, G.L., W.F. Megahan, and J.G. King. 1999. "R1-R4" and "BOISED" sediment prediction model tests using forest roads in granitics. *Journal of the American Water Resources Association* 35 (1):83-98.

Kochenderfer, J. N., P. J. Edwards, and F. Wood. 1997. Hydrologic impacts of logging an Appalachian watershed using West Virginia's best management practices. *Northern Journal of Applied Forestry* 14 (4):207-218.

Kochenderfer, J. N., and P.J. Edwards. 1990. Effectiveness of three streamside management practices in the Central Appalachians. In

Proceedings of the Sixth Biennial Southern Silvicultural Research Conference. Memphis, TN.
Kreutzweiser, D. P., and S. S. Capell. 2001. Fine sediment deposition in streams after selective forest harvesting without riparian buffers. *Canadian Journal of Forest Research* 31 (12):2134-2142.
Lakel, W.A., W. M. Aust, C.A. Dolloff, and A.W. Easterbrook. 2006. Soil erosion from harvested sites versus streamside management zone sediment deposition in the Piedmont of Virginia. In *Proceedings of the 13th Biennial Southern Silvicultural Research Conference*, edited by K. F. Connor: Asheville, NC: USDA Forest Service Southern Research Station.
LeDoux, C. B., and E. Wilkerson. 2006. A case study assessing opportunity costs and ecological benefits of streamside management zones and logging systems for eastern hardwood forests. Newtown Square, PA: USDA Forest Service Northern Research Station.
Martin, C. W., and J. W. Hornbeck. 1994. Sediment yields from undisturbed and intensively harvested northern hardwood forests. In *Proceedings of the 22nd Annual Hardwood Symposium of the Hardwood Research Council*.
McDonald, T.P., E.A. Carter, and S.E. Taylor. 2002. Using the global positioning system to map disturbance patterns of forest harvesting machinery. *Canadian Journal of Forest Research* 32:310-319.
Michels, O. 2009. GPS and GIS application and analysis of timber harvesting operations on steep terrain, Auburn University, Auburn, Alabama.
Miller, W. L., and H. W. Everett. 1975. The economic impact of controlling nonpoint pollution in hardwood forest land. *American Journal of Agricultural Economics* 57 (4):576-583.
Overstreet, J.C. 1984. Robinson Forest Inventory 1980-1982. Lexington, KY: University of Kentucky College of Agriculture, Department of Forestry.
Rashin, E. B., C. J. Clishe, A. T. Loch, and J. M. Bell. 2006. Effectiveness of timber harvest practices for controlling sediment related water quality impacts. *Journal of the American Water Resources Association* 42 (5):1307-1327.
Stringer, J., L. Lowe, M.F. Smidt, and C. Perkins. 1998. *Field guide to best management practices for timber harvesting in Kentucky*. FOR-69 ed: University of Kentucky, Cooperative Extension Service, Department of Forestry.
Stringer, J., and C. Perkins. 2001. *Kentucky forest practice guidelines for water quality management*. FOR-67 ed: University of Kentucky, Cooperative Extension Service, Department of Forestry.
Stringer, J., and A. Thompson. 2000. Comparison of forestry best management practices. Part 1: Streamside management zones. *Forest Landowner* 59:22-27.
Stuart, G. W., and P. J. Edwards. 2006. Concepts about forests and water. *Northern Journal of Applied Forestry* 23 (1):11-19.
Stuart, W.B., and J.L. Carr. 1991. Harvesting impacts on steep slopes in Virginia. Newton Square, PA: USDA Forest Service Northeastern Experiment Station.
Summer, W.B., C. Rhett Jackson, D. Jones, and M. Miwa. 2006. Dry Creek long-term watershed study: effects of timber harvest on hydrology and sediment export in headwater streams in southwest Georgia. In *Proceedings of the 13th Biennial Southern Silvicultural Research Conference*, edited by K. F. Connor: Asheville, NC: USDA Forest Service Southern Research Station.
Swank, W. T., J. M. Vose, and K. J. Elliott. 2001. Long-term hydrologic and water quality responses following commercial clearcutting of mixed hardwoods on a southern Appalachian catchment. *Forest Ecology and Management* 143 (1/3):163-178.

Swift, L.W. Jr. 1988. Forest access roads: design, maintenance, and soil loss. In *Forest Hydrology and Ecology at Coweeta*, edited by W. T. Swank and D. A. Crossley. New York: Springer-Verlag.

Taylor, S.E., T.P. McDonald, M.W Veal, and T.E. Grift. 2001. Using GPS to evaluate productivity and performance of forest machine systems. Paper read at First International Precision Forestry Symposium, June 17-19, at Seattle, WA.

Trimble, G.R., and R.S. Sartz. 1957. How far from a stream should a logging road be located? *Journal of Forestry* 55:339-341.

U.S. Department of Agriculture, Natural Resources Conservation Service. 2010. *Soil Survey Geographic (SSURGO) database for Breathitt County, Kentucky* U.S. Department of Agriculture, Natural Resources Conservation Service 2009 [cited April 27 2010]. Available from http://SoilDataMart.nrcs.usda.gov/.

Veal, M.W, S.E. Taylor, T.P. McDonald, D.K. McLemore, and M.R. Dunn. 2001. Accuracy of tracking forest machines with GPS. *Transactions of the ASAE* 44 (6):1903-1911.

Wynn, T. M., S. Mostaghimi, J. W. Frazee, P. W. McClellan, R. M. Shaffer, and W. M. Aust. 2000. Effects of forest harvesting best management practices on surface water quality in the Virginia coastal plain. *Transactions of the ASAE* 43 (4):927-936.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Project Title

Improved Skidding for Small Scale Biomass Harvesting Systems

Date:

October 23, 2009

- **Abstract**: Demand for renewable biomass products is growing every year and will likely increase as biomass consuming facilities are completed. Systems that can efficiently harvest and deliver this material in an environmentally friendly manner will be needed. The development of these systems should also address other problems facing the natural resources community such as forest fragmentation, the wildlife-urban interface and stands described as overstocked by the Healthy Forest Initiative. Small diameter trees are currently underutilized because systems that can economically harvest them are not available. Auburn University's School of Forestry and Wildlife Sciences has been researching a small-scale system to address these concerns, but the skidding function needs more investigation. The objective of this project will be to make improvements in the skidding operation to reach the productivity levels necessary to make small scale harvesting an economically feasible alternative to supply woody biomass to developing markets. Development and demonstration of an efficient, cost-effective system should lead to quick adoption by the logging community.

Key Personnel: Taylor Burdg and Tom Gallagher, School of Forestry and Wildlife Sciences, Auburn University;

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

How adequate are equipment replacement models for logging contractors?

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Abstract

Canadian logging contractors use their harvesting equipment seasonally, intensively, in extreme weather conditions, and in remote geographical locations. These factors lead to rapid machinery deterioration. Machine reliability is vital and harvesting contractors must replace production equipment regularly to assure operational continuity. Fixed-asset management choices involve significant amounts of money and can jeopardize the financial situation of a company. This is a major concern since harvesting contractors' machine replacement strategies are mostly informal and based on personal intuition. Managerial decision based on comprehensive analysis should determine the appropriate time for machine replacement, taking into account after-tax cash flows and proper maintenance strategies. Adopting an economic replacement model could guide decision making and improve harvesting contractor's overall performance. This paper presents an ongoing review of equipment replacement models and proposes characteristics of an effective machine replacement model meeting the needs of forest harvesting contractors in Eastern Canada.

Key words: economic analysis, machine replacement, fixed assets management, forest harvesting contractors, loggers, Canada, Quebec

1 Introduction

A prerequisite for today's harvesting contractors is to own one or several pieces of sophisticated and expensive production equipments. The need for reliable and dependable operations should compel forestry contractors to follow proper maintenance procedures and equipment replacement strategies. However, this is simply not the case; a recent study shows that machine replacement decisions made by logging contractors in Québec are based on intuition and experience (Vaillancourt, 2009). Although replacement economic models and specialized, out-of-the-box software exist today, forest contractors prefer to follow vernal maintenance or replacement calendars, without utilizing analysis built on sound economic principles.

Large enterprises have the capability to establish corporate guidelines to determine and follow engineered replacement policies, as suggested by several authors (Drinkwater & Hastings, 1967; Drake *et al.*, 1988; Jardine, 1984; Hide *et al.*, 1990; Simms *et al.*, 1982; Mahon & Bailey, 1975; Dreyfus, 1960; Schaevitz, 1988). However, Canadian logging operations are mostly carried out by relatively small independent contractors (Mercure, 1996; Legendre, 2005). In Eastern Canada, the median forestry harvesting contractor harvests approximately 60,000 tons per year, has one customer, employs four employees, and owns two machines (PREFoRT, 2007). In such context, implementing a formal machine replacement policy is not viewed by the entrepreneur as a critical need (Vaillancourt, 2009). However, machine replacement strategies used by such small independent contractors are important, and neglecting such issues could result in significant financial loss. While many entrepreneurs have neither expertise nor background to use complex software, their professional service providers (accountants, financial advisors) could be interested in such models. Thus, it is worthwhile to investigate adequacy of current machine replacement models for small independent logging contractors. The objective of this paper is therefore to present a review of equipment replacement models currently available and to propose characteristics of an effective machine replacement model meeting the needs of forest harvesting contractors.

2 Literature review

2.1 The replacement problem

Bonhomme & Lebel, (2003) carried out a financial analysis of 20 forestry contractors based on actual cost data. Their results showed that forestry contractors replacing machines more often exhibited low repair, maintenance, fuel, and lubricant costs, but at the same time high capital costs. The pattern was exactly the opposite for contractors exploiting to maximum equipment life. This evokes the basic conflict in replacement theory, where there is a tradeoff between operating and ownership costs as a function of age (Figure 1). When all costs are considered, the cost function exhibits a global minimum, corresponding to the optimum replacement age. In the sample cited before, forest harvesting contractors owning newer machines had total production costs 14% to 36% lower (Bonhomme & LeBel, 2003).

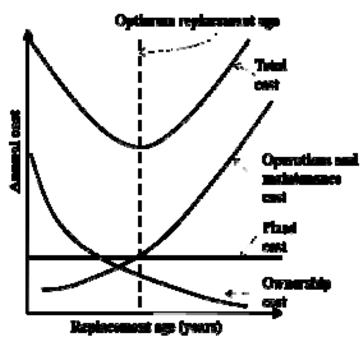

Figure 1. Optimum replacement age (adapted from Jardine & Tsang, 2006)

Replacement theory was first formalized in economics, based on depreciation studies (Hotelling, 1925; Taylor, 1923). Modern industrial applications are related to reliability engineering (Nakagawa, 2005; Jardine & Tsang, 2006). In this field, systems [forest harvesting machines for this paper] exhibit failure rates over time that can be illustrated by a *bathtub curve* (Figure 2). The figure is composed of three distinctive phases. In the first phase called *infant mortality*, failure is caused by learning curves, defects, or setup errors. The second phase represents most of the useful life; failure rate, mainly caused by random events, is relatively constant. In the last phase, increasing failure rate due to wear brings about sharp increases in repair and maintenance cost. It is in this stage that replacement (or repair) of a machine becomes suitable. Finding optimum replacement age is the basic replacement theory problem (Mathew & Kennedy, 2003; Nakagawa, 2005).

Figure 2. Bathtub curve with the normal failure periods of a system (adapted from Ait-Kadi, 2010)

There are numerous models in replacement theory (Jardine & Tsang, 2006; Mathew & Kennedy, 2003; Nakagawa, 2005; Wafer, 1997). Among the most cited are:

1. *Replacement of equipment used regularly while minimizing costs.* This model uses the minimum equivalent cost as a replacement criterion and assumes infinite horizon (i.e., replacing indefinitely for the same machine). Although impractical, this hypothesis simplifies mathematical computing. One attribute of this model is that it can be used to compare different machines. In forestry, the underlying equations used by Lussier (1961); Tufts & Mills Jr. (1982); and Sinclair *et al.* (1986) is derived from this model.
2. *Equipment used regularly while maximizing profits.* This model assumes continuous compounding and cash flows. It can be used to deal with changing revenues, considering different output levels, downtime, or need to quantify cash outflows during replacement (item normally discarded). It can be used to compare different machines.
3. *Establishment of economic life of equipment with variable use while minimizing costs.* This case could be used with redundant equipment (e.g., in fleets where similar equipments are used in different utilization ratios).
4. *Decision to replace for technologically superior equipment*. This model determines optimal moment to replace existing equipment with technologically superior equipment (finite planning horizon) and optimal replacement age for new equipment (infinite planning horizon).
5. *Repair limit theory.* This method establishes a rule dictating replacement when machine exceeds repair limit cost, obtained from expected failure.
6. *Delayed replacement.* Here decision to replace is prolonged until some criteria are met.

In forestry, all machine replacement models found in literature are formulated from economic analyses. They originally were based on costing estimations to determine *forecasted cumulative hourly costs* (Caterpillar Tractor Co., 1978; Miller, 1973; Sinclair *et al.*, 1986). Main drawbacks of these models are not accounting for taxes and ignoring time value of money (Butler & Dykstra, 1981; Tufts & Mills Jr., 1982; Sinclair *et al.*, 1986). Another existent type of machine replacement models in forestry are founded on *discounted cash flow analysis* (Lussier, 1961; Butler & Dykstra, 1981; Tufts & Mills, 1982; Stenzel, *et al.* 1985; Sinclair, *et al.* 1986; Caulfield & Tufts, 1989). These models are precise when calculating tax and financial components, but still use costing estimations for other items (e.g., repair and maintenance, fuel, and others).

Other related costing methods in forestry were created to calculate the machine rate (Bilek, 2007; Bright, 2004; Brinker, *et al.*, 2002; Burgess & Cubbage, 1989; Caterpillar Inc., 2002; FAO, 1992; Lussier, 1961; Matthews, 1942; Miyata, 1980; Sundberg & Silversides, 1988). Machine replacement models and machine rates methods have different purposes. *Machine replacement models* help to determine when machine replacement should take place, whereas *machine rates* are largely used by logging contractors, among others, to:

(1) determine revenue;

(2) negotiate with potential customers;

(3) use as a charge-out rate for accounting purposes or to compare machine performances;

(4) estimate break-even point;

(5) find out how to allocate fixed costs throughout the expected equipment life.

Machine rate models based on cash flow analysis consider future and incurred costs, while machine replacement models based on cash flows consider only forecasted amounts and treat all incurred expenses as sunk costs (i.e., not affecting future net cash flow). Evidently, both machine rate and machine replacement models rely on acceptable estimates for their cost components and are built from the same underlying theory. The only way to effectively use machine rate methods to calculate machine replacement age would be (a) to consider only forecasted elements (expenditures and productive hours) and (b) to adapt both algorithms to include many different possible economic life ages (age is in fact an input to the machine rate models; a valid alternative without changing algorithms is to solve models for a range of different possible ages). If using machine rate methods, criteria dictating economic life of equipment is age for which hourly rate is minimal.

Likewise, machine rates procedures (Bright, 2004; Brinker *et al.*, 2002; Miyata, 1980) may be useful when estimating some cost components for a machine replacement analysis. Alternative procedures for some independent cost components can also be applied (Howard, 1991; MacDonald, 2003; Werblow, 1986; Cubbage *et al.*, 1991).

2.2 Machine replacement practices in forestry

Butler & LeDoux (1980) cite a 1975 survey noting that excessive maintenance, repair and downtime costs were the first indicators to replace equipment. In their own survey, conducted five years later in the Pacific Northwest, they showed that few harvesting machines were being replaced beyond their economic life. Reasons cited for replacement motivations, in order of importance, were: tax advantages, former machine worn out or obsolete, and new machine better designed.

Rickards (1980) noted the absence of formal machine replacement policies in the industry. The analysis employed to determine the moment of replacement was based on cumulative hourly costs, but with inadequate distinction of the base hours employed (i.e., machine, engine, or productive hours). He urged the need to carry out machine replacement analysis founded on sound models accounting for depreciation, taxes, maintenance & repair, downtime, and financial components.

As for maintenance and repair, two studies have suggested that employing qualified mechanics could help forestry contractors increase equipment availability and reduce the need for replacement (D'Amours, 1999, Franklin & Williams, 1990). It has been noted that machinery owners typically use two different philosophies, (a) acquisition of new equipment designed to maximize availability with minimum maintenance, and (b) moderate utilization with significant maintenance to extend the useful life (Franklin & Williams, 1990). Financial impact of these two replacement strategies can vary capital expenses, from 30% of total cost for newer machines, to 10% of total cost for older equipment (Bonhomme, 2003). Conversely, maintenance and repairs expenses were around 16% of total cost for newer machines and up to 30% for old ones; in the case of lubricants and fuel consumption, the figures fluctuated from 9% for new machines to twice as much for old equipment. Resulting total production costs were around 14% to 36% lower for newer machines in the sample of forest contractors analyzed by the author. It is important to mention that these figures did not take into account working capital tied up for spare parts kept in inventory.

3 Materials and methods

Two different sources of information are employed to achieve the research objective:

a) The first source covers an examination of forest harvesting contractors' managerial practices related to machine replacement. The information was obtained from logging contractors via two surveys: a first one in the fall of 2006 (PREfoRT, 2007; Drolet & Lebel, 2010), and a follow-up in the fall of 2009 (analysis in progress). Additionally, 46 individual meetings with selected forest harvesting contractors took place in 2008 (Vaillancourt, 2009).

b) For the second source, a critical review of machine replacement methods found in the forestry literature was carried out.

Using these two sources of information, a gap analysis was then performed between present needs of forest harvesting contractors and machine replacement models available.

4 Analysis and discussion

4.1 Forest harvesting contractor managerial practices

We analyzed empirical data to determine factors affecting replacement decisions for a forest harvesting contractor. Information presented here comes from three different research actions led by the Harvesting and Transport Forestry Contractors Research Program (PREfoRT):

1. **2006-2007 PREfoRT survey**. In 2006 and 2007 PREfoRT surveyed 2,540 forestry contractors in the province of Québec, Canada regarding forest harvesting, roading, and transport. It is believed that the entire population of harvesting contractors in Québec was surveyed. The results discussed below show highlights from responses of 336 valid questionnaires returned by forest harvesting contractors (PREfoRT, 2007). Survey design details can be found in Drolet & Lebel (2010).
2. **2008 individual meetings.** In 2008, PREfoRT carried out individual meetings with selected harvesting contractors who responded to the 2006-2007 survey. The purpose of this study was to further explore forestry contractors' managerial practices. Details of these meeting can be found in Vaillancourt (2009).

3. **2010 follow-up survey**. In the fall of 2009, a follow up survey was prepared with the objective of studying evolution from 2006-2007. While data compilation has been completed; analysis is still in progress. This paper draws responses related to machine replacement only.

Asset buying preferences in the 2006-2007 survey revealed that 55% of respondents buy only new equipment, 35% only buy used equipment, and 10% will buy either new or used equipment. From the 2008 meetings, we learned that the main source of financing to acquire new machinery was bank loan (78%). A quarter preferred to buy with equity (Table 1). One concern repeatedly expressed in 2010 is that the decision to replace is normally delayed until customers' contracts are assured, at least informally.

Table 1. Financing sources to buy machinery

Strategies for financing equipment (2 choices, 91 answers)	n (46)	%
Bank loan	36	78
Equity	13	28
Credit line	5	11
Shares issue	3	7
Loan of a major buyer	2	4
Others	2	4

The 2008 individual meetings have allowed determining the main criteria used to select equipment (Table 2). Participants gave the greatest importance to reliable equipment with cost ranking second. It must be reported that a majority of participants were working out of remote camps. In this situation, service and repair must be assumed by the entrepreneurs themselves. In the case where a mechanic or technician is required, cost can be significant. Moreover, lost production cannot be recovered since contracts do not usually guarantee a specific volume to the contractor. Production lost by a logger in one procurement area, is gained by the other loggers who share that area.

Table 2. Criteria used to choose forestry equipment

Main criteria used to select machinery (2 choices, 90 answers)	n (46)	%
Reliability	27	59
Acquisition cost	20	44
After-sales service and good dealer relationship	12	26
Equipment size and performance	10	22
Oil consumption	9	20
Technological advance	6	13
Compatibility of parts in stock vs. parts of a new machine	5	11
Norms and environment compliance	1	2,2

A practice mentioned in the 2008 individual meetings stated that harvesting contractors replaced their machinery based on personal experience and intuition. Replacement policies were absent in 50% of all cases, with only 5% of participants having a written replacement strategy, and the rest carrying it out informally. The 2010 follow up survey's results indicate that only 40% out of 171 participants used some sort of formal analysis. However, a deeper analysis indicates that only 23% use what qualifies as sound analysis (e.g. cash flow or hourly rate analysis), or professional consultant recommendation.

According to the 2006-2007 PREfoRT survey, over 50% of all forestry contractors keep machinery for more than five years. These results were confirmed again during the 2008 individual meetings. Forest harvesting contractors operating in private forest replace their machinery less often than those in public forest. When a machine breaks down in a private forest, harvesting can be postponed until the machine is repaired, and lead time for parts is usually shorter. Loggers working in public forest are constrained by time and, more importantly, by a maximum production quota that could be filled by another logger. Another constraint for the loggers in public sector is lead time for parts or spare machines; public forest operations are mostly far from cities. Public forest in Québec provides around 80% of commercial timber (MRNF, 2010).

Table 3. Average age of asset replacement*

Average age of asset replacement (years), n=44	Public forest			Private forest			Public and private		
	n	X	%	n	x	%	N	x	%
	32	6,6	72,7	9	15	20,5	3	8,3	6,8
Less than 5	5	- -	11,4	2	- -	4,5	0	- -	0
5 – 7	20	- -	45,5	0	- -	0	1	- -	2,3
8 – 10	5	- -	11,4	0	- -	0	2	- -	4,5
11 or more	2	- -	4,5	7	- -	15,9	0	- -	0

*Note: that some respondents use their equipment 24 hours per day while others only during an 8 shift.

4.2 *Replacement models in forestry literature*

We reviewed nine different replacement models found in the forestry literature:

1. Lussier (1961)
2. Caterpillar (1978)
3. Butler & Dykstra (1981)
4. Tufts & Mills (1982)
5. Mills & Tufts (1985)
6. Stenzel, *et al.* (1985)
7. Sinclair, *et al.* (1986), before-tax, "simple model"
8. Sinclair, *et al.* (1986), after-tax, "complex model"
9. Caulfield & Tufts (1989)

The above list represents models found so far in our research. They are all directly addressing the issue of machine replacement in forestry. The analysis presented next is based on hypotheses and supporting theory upon which these models are built.

The Butler & Dykstra (1981) model represents an upgraded version of a previous paper (Butler & LeDoux, 1980) which is excluded from the current analysis since both models use the same equation. Mills & Tufts (1985) compare models proposed by Butler & Dykstra (1981) and Tufts & Mills (1982) and clarify the latter, including details for borrowed funds. Another paper related to machine replacement (Miller, 1973) was excluded from this analysis because the paper does not describe a model *per se*. It only describes general recommendations to include compound interest and inflation in machine replacement analysis.

4.2.1 Analysis

Table 5 summarizes our comparisons of the nine models. All models have been produced specifically to assist in determining replacement policy of forestry equipment. All are founded on costing analysis, making use of either cash flows or cumulative hourly costs. All common cost items were removed in Table 4 because original models understate or explicitly describe the following cost items: storage, insurance, purchasing price, salvage value, depreciation, maintenance, repairs, fuel, oil, lubricants, tires, wages, overhead, and license fees. Purpose of all models presented is to calculate economic life of equipment being analyzed. All models require costing estimates forecasting periods ahead. In addition, analyses consider all incurred expenses as sunk costs, except for Caterpillar (1978), and Sinclair *et al.* (1986), where previous disbursements are cumulative.

Analysis of these models reveals that the most important element of all models is developing sound forecasts of cost components. The list of cost items is not necessarily the same for every analysis. Differential items (costs or revenue) that change from one situation to another are important. All models are of practical orientation and none use continuous compounding or probability distributions. Indeed by analyzing the needs of forest harvesting contractors, there is nothing justifying the inclusion of more complex parameters, (e.g. exponential, or probability density functions). Existence of a useful life is independent of age of economic replacement except when the former is shorter. Because of this, analysis with non convex cost functions should consider a horizon equal to the expected useful equipment life. All methods should privilege a life cycle cost perspective, that is, to include all cash flows through the life of the equipment, including disposal. Basic computation structure for each model is to obtain figures for one period, as if the machine was going to be sold in that particular period; this is repeated successively for all periods.

Sinclair *et al.* (1986) demonstrated in their paper that machine replacement models using equivalent yearly cost and cumulative hourly cost give similar results. Even if their calculations do not take into account downtime or precise depreciation equations, their findings explain why a cumulative hourly rate model is valid, being a good option for a forestry contractor using nothing to decide when to replace machinery. In addition, they demonstrated with empirical data that machines having a steeper maintenance and repair cost curve are more sensitive to optimal replacement time.

Table 4. A synthetic review of equipment replacement models in forestry

Model	Mix of borrowed funds	Inflation	Taxes and credits	Downtime costs	Risk	Technological change	Different output levels	Unequal lives	Utilization criteria	Replacement criterion
Lussier (1961)				✓				✓	Productive hours or machine time	Minimum equivalent cost
Caterpillar (1978)		✓	✓ (3)	✓		✓			Productive hours	Minimum cumulative hourly cost
Butler & Dykstra (1981)		✓	✓	✓		✓ (1)			Productive hours	Minimum cumulative-average discounted total cost
Tufts & Mills (1982)		✓	✓			✓ (1)		✓	Productive hours	Minimum equivalent cost
Mills & Tufts (1985)	✓	✓	✓	✓		✓ (1)		✓	Productive hours	Minimum equivalent cost
Stenzel, *et al.* (1985)		✓	✓			✓	✓		Productive hrs cords	Net present value
Sinclair, *et al.* (1986), simple		✓ (2)				✓	✓		Productive hours + tonnes or km	Cumulative hourly costs
Sinclair, *et al.* (1986), complex		✓ (2)	✓					✓	Productive hours + tonnes or km	Minimum equivalent cost
Caulfield & Tufts (1989)		✓	✓	✓	✓	✓ (1)		✓	Productive hours	Minimum equivalent cost

Notes:

Legend: ✓ YES

(1) No when different output or revenue levels are used among the options

(2) Effect removed to calculate regression on Repair & Maintenance

(3) Approximate computing method

Two important factors not considered by any of these models are working capital and variable utilization. Working capital is the current assets minus current liabilities (Hilton, 1999) and is important because it can affect changes in net cash flow due to spare parts maintained in inventory. Variable utilization applies when a machine is not necessarily to be used at a constant rate within a year. All models in Table 4 supposed constant yearly utilization periods.

When borrowed funds are used to finance a machine, tax treatment, rate of return and net cash flow are affected. First, borrowed funds increase net cash flow, eliminating or reducing the need for equity to buy equipment. Even if repayment must cover borrowed funds and associated interest, it is done in periods ahead, thus not affecting liquidity. In addition, the tax system often allows interest to be deductible. Finally, in some cases, choosing a mix of debt and equity can help increase net present value of an investment project (Fraser *et al.*, 2000). The rate of return must be adjusted if borrowed funds are invested; the rate used to compute discounting must take into account the contractor's interest on borrowed funds and expected return. Most forest contractors simply do not have the required equity to buy machinery, thus including borrowed funds in the analysis is an important criteria when choosing a model. Although most models recognize the possibility of repayment as another expense, only the model of Mills & Tufts (1985) makes a proper distinction on tax treatment for borrowed funds.

The problem of selecting among different machines can be solved efficiently by applying any model included in Table 4, for each different alternative. However, to make things comparable, options need to have comparable equipment in terms of total useful life and output. The only models capable of handling correctly unequal useful lives are those whose decision criteria is based on minimal equivalent cost (Galibois, 1997). For the situation of different output production levels, all models could be adjusted by adding inflow costs (i.e. a "positive cost" reduces "negative costs"). Only Stenzel *et al.* (1985) propose a model capable of taking into account different output levels without adjusting. They do so by using net present value as a decision criterion.

Technological change is partially solved in various models of Table 4. These models advocate inclusion of technological change as an opportunity cost. As Butler & Dykstra (1981) point out, this logic ignores whether or not the forestry contractor can potentially sell, or would indeed use, this extra performance. Considering technological change as an expense neglects possible changes in net cash flow. As a result, expenses for current machine would be penalized, forcing early replacement.

The models of Tufts & Mills (1982) and Sinclair *et al.* (1986) use the same basic equation as proposed by Lussier (1961). However, Tufts & Mills (1982) describe a precise financial treatment that is still valid. In a later paper, supporting equations and hypotheses are clarified (Mills & Tufts, 1985). Additionally, the authors add a treatment on borrowed funds making this model superior, in theoretical terms, over all the others. Finally, what differentiates Sinclair *et al.* (1986) *complex model* is the presentation of a useful approximation to estimate ownership cost also used in their *simple model*.

Caulfield & Tufts (1989) present a model that accounts for risk. The procedure could be of little use for a forestry contractor with no historical data, but helpful if the manager is concerned with uncertainty. The difficulty of adding risk to the analysis could be greatly simplified by adjusting rate of return used for discounting by a risk premium covering for worst case, or by adding a sensitivity analysis for various assumptions like revenue, oil price, or working hours. This is highly suggested since, as noted from the previous section, contractors do not usually replace their equipment until having at least verbal confirmation of a possible contract.

In their proposed model, Butler & Dykstra (1981) add a discounting factor, and provide a practical way to compute maintenance and downtime. The procedure and cost items are represented through formulas and an algorithm for mathematical, non-linear programming. Major flaws for this model are 1) use of cumulative average discounted total cost as decision criterion and 2) financial treatment which is less precise than what is proposed by Tufts & Mills (1982). Downtime due to unplanned failure is critical and must be considered.

Existing models could be further improved by integrating precise cost calculations, uncertainty, reliability, planned inspections, and provisions for preventive maintenance strategies. However, this is quite ambitious, as survey data shows that most contractors do not even use the simplest of models. This is preoccupying; equipment replacement decisions are not trivial. They involve large amounts of money, risk and are usually the largest asset in a forest harvesting contractor's business. We therefore propose to adapt an existing simplified model that would combine some of the best features of existing models.

We believe that the models proposed by Lussier (1961), Tufts & Mills (1982), Mills & Tutfs (1985), and Stenzel *et al.* (1986) represent the best alternatives based on use of sound investment theory. Working capital and risk premiums should be integrated to the proposed model. Maintenance management is key to successful asset management. A model built on spreadsheet technology that have graphical feedback to present the information, can allow for easy adoption. Any model will need to be used periodically, according to simple business rules, and continuous monitoring process of the main variables of interest. It could be a component of a performance dashboard (Lepage & LeBel, 2007). If one of these variables reaches or deviates from boundaries, then an analysis should be made. Finally, harvesting contractors owning more than one machine should be monitoring more closely machines that have steeper curves of repair and maintenance costs. Analysis of for this type of equipment demand more precise cost estimates on repair, maintenance, and unplanned downtime.

5 Conclusions

Forest harvesting contractors are conducting business without using methods that could help them manage machine replacement efficiently. Implementing a model adapted to local tax regulations and based on sound investment theory can improve performance and reduce risk. The approach should privilege an emphasis on training, sensitization, and promotion. Although it is utopian to expect all forest contractors to use such financial analysis tool, it should be expected that supporting agent such as equipment dealerships, accountant or loan officer can rely on such models. All contractors should be expected to provide reliable data regarding equipment utilisation, maintenance and repairs.

The adapted model should be built on a spreadsheet, be easy to use and include risk, working capital, borrowed funds management, downtime estimation, and sensibility analysis. The method should be used periodically on an iterative process, with re-planning triggered by deviation of key performance indicators beyond critical thresholds.

6 Bibliography

Ait-Kadi, D. (2010). *Gestion de la maintenance, notes du cours.* Québec, Québec: Université Laval.

Bilek, E. M. (2007). *ChargeOut! Determining Machine and Capital Equipment Charge-Out Rates Using Discounting Cash-Flow Analysis.* Forest Service, Forest Products Laboratory. Madison: United States Department of Agriculture.

Bonhomme, B. (2003). *Évaluer la performance des entreprises d'exploitation forestière québécoises par les critères de rentabilité financière et d'efficience technique.* Mémoire de maîtrise en sciences, Université Laval, Faculté de foresterie et géomatique, Québec.

Bonhomme, B., & LeBel, L. (2003). Harvesting Contractors in Northern Quebec: A Financial and Technical Performance Evaluation. *COFE Annual Meeting.* Bar Harbor, Maine: Council on Forest Engineering.

Bright, G. (2004). Calculating costs and charges for forest machinery use. *Forestry , 77* (2), 75-84.

Brinker, R. W., Kinard, J., Rummer, B., & Lanford, B. (2002). *Machine Rates for Selected Forest Harvesting Machines.* Auburn: Alabama Agricultural Experiment Station.

Burgess, J. A., & Cubbage, F. W. (1989). Comparison of machine rate and cash flow approaches for estimating forest harvesting equipement costs. *1989 ASEA winter meeting presentation.* New Orleans, Louisiana: American Society of Agricultural Engineers.

Butler, D. A., & Dykstra, D. P. (1981). Logging equipment replacement: a quantitative approach. *Forest Science , 27* (1), 2-12.

Butler, D. A., & LeDoux, C. B. (1980). *Scheduling replacement of logging equipment: some quantitative guidelines.* Oregon State University, School of Forestry. Corvallis, Oregon: Forest Research Lab.

Caterpillar Inc. (2002). *Guide Caterpillar Matériels et Méthodes.* Peoria: Caterpillar Inc.

Caterpillar Tractor Co. (1978). Don't guess; here are the facts on when to trade. *Canadian Pulp and Paper Industry* , 28-30.

Caulfield, J. P., & Tufts, R. A. (1989). Forestry equipment replacement decisions under risk. *Forest Products Journal , 39* (9), 49-54.

Cubbage, F. W., Burgess, J. A., & Stokes, B. J. (1991). Cross-sectional estimates of logging equipment resale values. *Forest Products Journal , 41* (10), 16-22.

D'Amours, F. (1999). *Étude du contexte opérationnel des entrepreneurs forestiers en forêt boréale québécoise.* Mémoire de maîtrise en sciences, Université Laval, Faculté de foresterie et géomatique, Québec.

Drake, R. W., Carter, D. W., & Gaudette, J. J. (1988). *Transit Capital Investment to Reduce Operating Deficits – Alternative Bus Replacement Strategies.* Washington: Transportation Research Board.

Dreyfus, S. E. (1960). A Generalized Equipment Replacement Study. *Journal of the Society for Industrial and Applied Mathematics , 8* (3), 425-435.

Drinkwater, R. W., & Hastings, N. J. (1967). An Economic Replacement Model. *Operational Research Quaterly , 18* (2), 121-138.

Drolet, S., & Lebel, L. (2010). Forest harvesting entrepreneurs, perception of their business status and its influence on performance evaluation. *Forest Policy and Economics , 12*, 287-298.

FAO. (1992). *Cost control in forest harvesting and road construction.* Rome: Food and Agriculture Organization of the United Nations.

Franklin, G. S., & Williams, W. A. (1990). *L'entretien de l'équipement par les entrepreneurs: problèmes et opportunités.* Pointe Claire: Institut Canadien de Recherces en Génie Forestier (FERIC).

Fraser, N. M., Bernhardt, I., Jewkes, E. M., & Tajima, M. (2000). *Engineering Economics in Canada* (éd. 2). Prentice Hall Canada.

Galibois, A. (1997). *Analyse économique pour ingénieurs.* Sainte-Foy: Éditions AGA.

Hide, H., Madrus, T., & Jang, K. (1990). Benefits to bus operators of introducing a comprehensive Life Cycle Costing System: A Practical Application. *Transportation Research Record , 1266*, 112-119.

Hilton, R. W. (1999). *Managerial Accounting.* McGraw-Hill.

Hotelling, H. (1925). A General Mathematical Theory of Depreciation. *Journal of the American Statistical Association , 20* (151), 340-353.

Howard, A. F. (1991). Improved Accounting of Interest Charges in Equipment Costing. *Journal of Forest Engineering , 2* (2), 41-45.

Jardine, A. K. (1984). *Maintenance Replacement and Reliability.* Pitman.

Jardine, A. K., & Tsang, A. H. (2006). *Maintenance, Replacement, and Reliability: Theory and Applications.* Boca Raton: CRC Press.

Legendre, C. (2005). *Le travailleur forestier québécois: transformations technologiques, socioéconomiques et organisationnelles.* Montréal: Presses de l'Université du Québec.

Lepage, D., & LeBel, L. (2007). (Conference) Evaluation of the needs of forest harvesting sub-contractors in developping performance dashboards. *3rd Forest engineering conference.* Mont-Tremblant, Canada: FEC-COFE.

Lussier, L.-J. (1961). *Planning and Control of Logging Operations.* (T. F. Foundation, Éd.) Québec, Québec, Canada: Université Laval.

MacDonald, A. (2003). *Coûts de réparation et d'entretien des équipements de récolte forestière.* Rapport Avantage, Feric, Canada.

Mahon, B. H., & Bailey, R. M. (1975). A proposed improved replacement policy for army véhicules. *Operational Research Quaterly , 26* (3), 477-494.

Mathew, S., & Kennedy, D. (2003). A Strategy for Optimal Equipment Replacement. *Production Planning and Control , 14* (6), 571-577.

Matthews, D. M. (1942). *Cost Control in the Logging Industry.* New York and London: McGraw-Hill Company.

Mercure, D. (1996). *Le travail déraciné : l'impartition flexible dans la dynamique sociale des entreprises forestières au Québec.* Montréal: Boréal.

Miller, R. K. (1973). Logging equipment replacement: a quantitative approach. *Forest Industries , 100* (2), pp. 32-33.

Mills Jr., W. L., & Tufts, R. A. (1985). Equipment replacement : A comparison of two methods. *Forest Science , 31* (3), 661-670.

Miyata, E. S. (1980). *Determining Fixed and Operating Costs of Logging Equipment.* North Central Forest Experiment Station, Forest Service. United States Department of Agriculture.

MRNF. (2010, 4 30). *Milieu foestier.* Récupéré sur MRNF: http://www.mrn.gouv.qc.ca/forets/quebec/quebec-milieu.jsp

Nakagawa, T. (2005). *Maintenance Theory of Reliability.* London: Springer.

Prefort. (2007). *Synthèse des résultats du sondage Prefort.* Université Laval, Opérations forestières. Québec: Prefort. Available on line at www.prefort.ulaval.ca.

Rickards, J. (1980). Capital Expenditure and Replacement Strategies in an Inflationary Economy. *LOG National Meeting.* Toronto: CPPA Logging Operations Group - Maintenance and Service Committee.

Schaevitz, R. (1988). Use of life-cycle cost analysis in transit capital overhaul/replace decisions – An application to the path railcar fleet. *Transportation Research Record , 1165,* 11-18.

Simms, B. W., Lamarre, B. G., Jardine, A. S., & Boudreau, A. (1982). Optimal buy, operate and sell policies for fleets of véhicules. *European Journal of Operational Research , 15* (2), 183-195.

Sinclair, A. W., Clark, M. L., & Wong, T. B. (1986). *Two Replacement Models for B.C. Coastal Logging Equipment.* Institut Canadien de Recherches en Génie Forestier (FERIC).

Stenzel, G., Walbridge Jr., T. A., & Pearce, J. K. (1985). *Logging and Pulpwood Production* (éd. 2nd). États-Unis: John Wiley & Sons.

Sundberg, U., & Silversides, C. R. (1988). *Operational efficiency in Forestry, Volume 1: Analysis.* Dordrecht, The Netherlands: Kluwer Academic Publishers.

Taylor, J. S. (1923). A Statistical Theory of Depreciation. *Journal of the American Statistical Association , 18* (144), 1010-1023.

Tufts, R. A., & Mills Jr., W. L. (1982). Financial Analysis of equipment selection. *Forest Products Journal , 32* (10), 45-52.

Vaillancourt, C. (2009). *Les comportements de gestion adoptés par les entrepreneurs de petite entreprise de récolte forestière au Québec.* Mémoire de maîtrise en gestion des organisations, Université du Québec a Chicoutimi, Département des sciences économiques et administratives, Chicoutimi.

Wafer, C. (1997). *Une approche intégrée pour l'exploitation et la gestion d'une flotte de véhicules.* Mémoire de maîtrise en sciences, Université Laval, Faculté des sciences et de génie, Sainte-Foy.

Werblow, D. A. (1986). Forest Harvesting Equipment Ownership and Operating Costs in 1984. *Southern Journal of Applied Forestry , 10* (1), 10-15.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Soil Disturbance and Site Impacts Related to a Thinning Operation in Kentucky

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Abstract

A study was undertaken in 2007 to evaluate the impact of implementing specific management prescriptions to sustain oak regeneration and improve forest health in the Daniel Boone National Forest, Kentucky, as outlined in the new Land and Resource Management Plan. Soil disturbance classes and soil impacts were evaluated for one method of stand regeneration: shelterwood with reserves. Soil disturbance classes were tabulated throughout the harvest stand while subsections of the stand were delineated and soil physical properties measured within each subsection. Soil physical properties were also measured in an unharvested stand in close proximity to the harvest tract. Soil disturbance class data and soil impact data will be presented.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Title: Forest Biomass Assessment and Transportation Analysis for Evaluating the Feasibility of Establishing a Biomass Power Plant in Northwest Oregon

Authors: Joshua Clark, John Sessions, Michael Wing, Christian Schmidt.

Abstract:
To meet state and national renewable energy goals, there is growing interest and support for utilizing biomass energy as an alternative source of electricity for communities in the Pacific Northwest. The cost of transporting biomass energy to a plant can be the largest cost component when utilizing biomass for energy. Recognition of the spatial variability of forest biomass relative to the surrounding road network is necessary to accurately estimate transport time, and its associated cost.

This study estimates forest biomass availability at 30 m resolution for all available forest land within about three hours of potential plant locations. This analysis considers forest industry landowner and state of Oregon management goals and then estimates the biomass transport cost for residues associated with commercial forest operations. The spatial availability of forest residues over a ten-year time frame is estimated.

The model combines a regional forest biomass assessment to a road database consisting of local, collector, and arterial roads. The transportation cost for implementing a 25 MW plant in northwest Oregon was then estimated for a ten-year time period. A cost analysis is conducted for various potential plant locations.

Introduction:

A variety of factors have led both private and public organizations across the country (including the Pacific Northwest) to explore the potential of forest biomass as a source of energy (Lord et al. 2006). Some of the primary reasons for utilization of forest residues include

- Local employment opportunities
- Potential to improve forest health
- Source of domestic energy.
- State and federal goals for renewable fuels

As interest increases in forest residues as a viable energy source, it is important to understand the cost of producing biomass energy, when compared to other current sources of energy (e.g., hydroelectric, fossil fuels). One of the major costs is incurred when transporting forest residues from roadside to a biomass plant.

The transportation cost is dependent on several factors (e.g., transport configuration and road conditions), but the predominant costs tend to be based on two major factors:

- The transport time between the source (biomass) and destination (plant)
- The moisture content of the forest residues.

Both of these factors must be considered to accurately estimate transportation costs on a regional basis. Our assessment area consists of northwest Oregon and southwest Washington (Figure 1). Once the transportation network and biomass distribution are modeled, it is possible to create a transportation cost model.

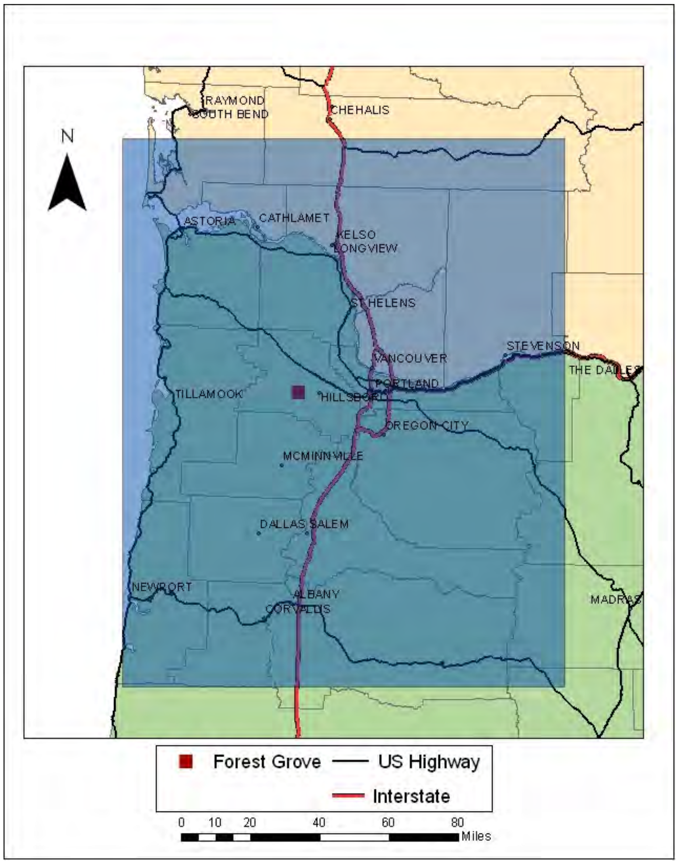

Figure 1. Biomass assessment area in northwest Oregon and southwest Washington.

Methods:

Biomass (Forest Residue) Model

In estimating forest biomass residues, the objective was to develop spatially explicit estimates for biomass that is likely to be available for a ten-year period, 2013-2022, using the available data sets. The primary vegetation set relied on the Landscape Ecology, Modeling, Mapping and Analysis (LEMMA) program (USDA 2010) and confirmed with major landowners. Three steps were taken to complete the biomass assessment, including

- Classifying the landscape into broad ownership classes
- Determining the spatial arrangement of each forest age class to find probable harvest areas

- Within each age class, estimating residual biomass available for biomass harvesting. Residual biomass was calculated from regional allometric biomass equations.

There are several public and private landowner types in the region (Figure 2). Both private industrial timberlands and state-owned lands were included in forest residue estimates. Residue harvest availability for other owners (federal and non-industrial private are less certain and were excluded as a potential source of forest residue for this study.

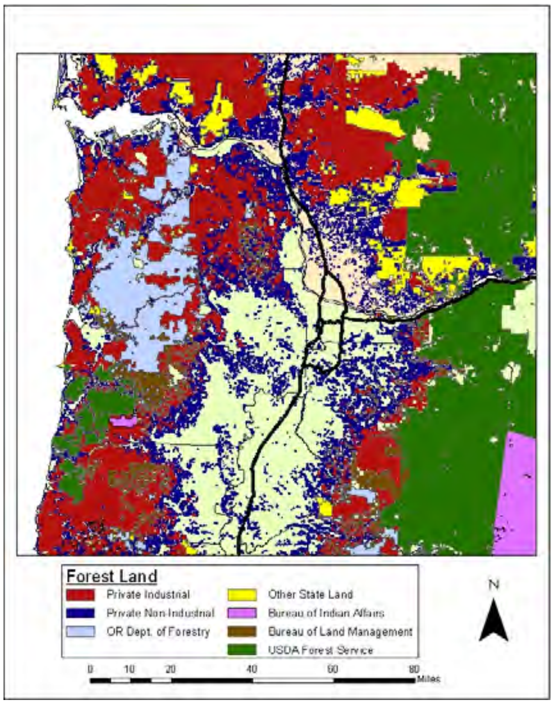

Figure 2. Land ownership map for the assessment area.

Transportation Model

Travel time can be estimated between a potential energy plant location and any road segment. However, forest residues are not located on the road, and the model must address three important factors:

- What will the road network include, and what travel speeds should be used?
- At what point will the transportation network begin – at the stump or roadside?
- What additional costs will be considered outside of hourly transport cost?

Road Network and Travel Speeds

It is possible to estimate the transport time if road types (and associated speeds for each road type) in the region are known. The data for Washington and Oregon roads was taken from the USDI Bureau of Land Management Ground Transportation, Roads and Trails (GTRN) databases for each state (USDI 2010). From this road network, road speeds were estimated by road class (Table 1). When implementing the road network in ArcGIS 9.3 (ESRI), the roads were changed from vector to raster format (Figure 3), with a spatial resolution of 30m x 30m. The time to cross each 30m x 30m pixel is calculated using the speed of the road type on that pixel.

Table 1. Estimated Travel Speeds for Oregon and Washington

	Speeds (mph)	
Road Type	Oregon	Washington
Interstate	60	60
State & Major Highways	50	50
Other Paved Roads	30	30
Undefined Roads	20	20
Local Roads	12	12

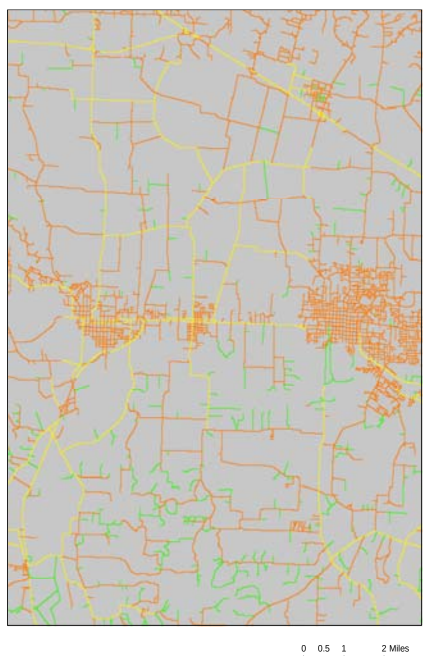

Figure 3. Road network – Forest Grove, OR (Left) and Hillsboro, OR (Right), where yellow are major highways, orange are other paved roads, and green are local roads

Where Will the Transportation Network Begin?

In order to accurately model transport time, the problem must be clearly defined. Three separate models were developed and tested, and each model can be used to estimate transport time. All three methods can be implemented with commercially available software (ArcGIS Spatial Analyst extension). They are listed below in order of implementation complexity.

In the first method the procedure was:

- Assign a transport speed for each road raster cell
- Assign a transport speed for all raster cells that are not roads (including fields, forested areas, etc). This speed can vary by land use type, but this study used a constant value ~4x slower than the slowest road speed (3 mph)
- Calculate the total time from each point (including non-road pixels) to the central location.

In the second method, the procedure was:

- Assign a transport speed (time) for each road pixel
- Calculate the total time from the central location to each segment of each road, using a function (Cost Weighted Distance) in Spatial Analyst
- Find the nearest road raster cell for every cell that does not belong to a road
- Assume that the travel time = 0 from stump to road. Assign each non-road pixel to a time value equal to the total time assigned to the nearest road pixel.

In the third method, the procedure was:

- Assign a transport speed (time) for each road segment
- Estimate the nearest road segment for each point
- Use a travel time for each non-road pixel to the road segment that is nearest the segment
- For each non-road pixel, estimate the total time to the central location by summing the time from central location to nearest road segment and the time from the nearest road segment to actual biomass location. This differs from the first method, which calculates shortest distance from the biomass location to central location, but does not necessarily travel to the nearest road location first.

Each method has advantages and disadvantages, and the problem should be carefully considered before deciding which method to use. With the third method, costs can be broken down into primary and secondary transport costs, with an associated distance for each mode of transportation. However, in order to fully utilize this information, harvesting techniques (e.g., cable vs. ground skidding), as well as several other factors (equipment, slopes, production rates) must be known for an area. This complexity is beyond the scope of this project, but remains a possibility in more advanced models, especially at a smaller spatial scope.

For this study, the second method was chosen. This analysis assumes that all biomass is picked up at roadside. Additional time from the nearest roadside to the biomass “at the stump” is not considered in the transportation time because the majority of the forest residues are generated either near the landing or at the landing during commercial forest operations. The forest residues for this particular study consider only the forest residues that are currently left at roadside or within a short forwarding distance by excavator to roadside. Since these forest residues are normally burned, the overall carbon effect of burning these residues in a biomass plant is carbon positive (assuming the energy is displacing energy that would have been from burning fossil fuel).

Additional Transportation Model Considerations

When considering total one-way travel time, an additional buffer of 15 minutes was included to account for miscellaneous stops, including

- Turnouts
- Intersection wait time
- Other unexpected stops (e.g. unscheduled maintenance).

When calculating the cost in this study, the following costs are included:

- Move-in ($)
- Forwarding to a central pile ($)
- Grinding at a central pile ($)
- Truck Delays ($)
- Transport ($/mi)
- Profit/Risk buffer (%)

Results:

Using the biomass and transportation models as inputs, a cost model was developed for six central locations in northwest Oregon. The models showed that the most cost-effective biomass plants were cogeneration plants, with some of the residual energy used for drying lumber. The six central locations were at existing saw mills. Several factors were adjusted to estimate break-even energy prices, including moisture content, alternative prices of mill residuals, and plant size.

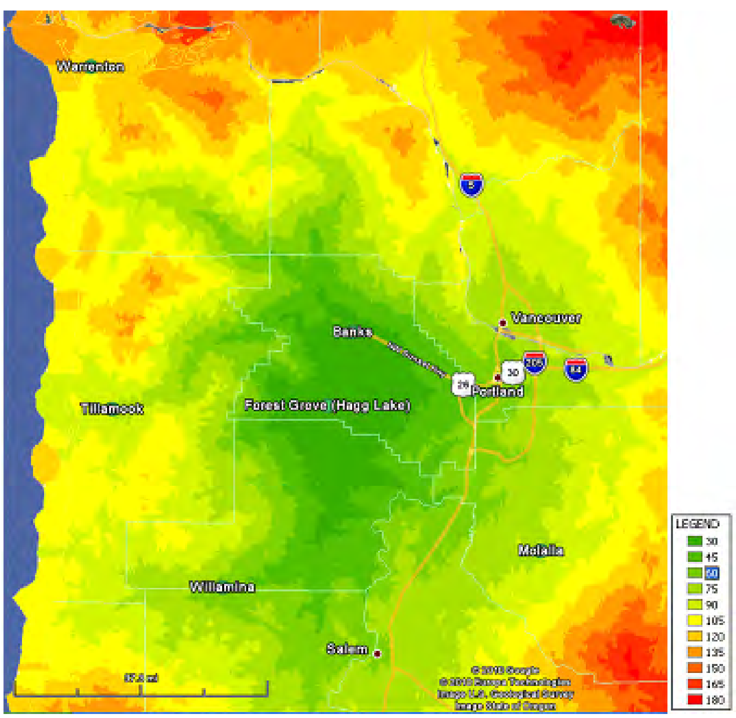

Figure 4: One-way travel times from Forest Grove (Hagg Lake)

Depending on the location of adjacent plants, it may not be sufficient to estimate the cost of biomass solely based on the spatial location of biomass but must consider competition between potential plants. Additional analysis examined potential conflict zones of overlapping demand. The premium price that a mill can pay is dependent on several factors, including fluctuating market conditions, existing contracts, and economics of scale.

		Tillamook											
	Minutes	30	45	60	75	90	105	120	135	150	165	180	>180
Astoria	30	0	0	2	6	9	6	0	0	0	0	0	0
	45	0	1	10	6	5	32	53	0	0	0	0	0
	60	0	3	7	9	7	5	24	5	0	0	0	0
	75	4	3	2	4	3	0	8	27	5	0	0	0
	90	3	0	2	0	4	3	7	7	22	4	0	0
	105	6	3	0	2	3	4	3	3	2	19	3	0
	120	0	8	3	2	3	1	3	1	2	7	24	2
	135	0	0	12	8	2	2	1	0	0	3	16	33
	150	0	0	0	13	6	2	2	0	0	0	2	32
	165	0	0	0	0	16	7	1	0	0	0	3	25
	180	0	0	0	0	0	13	4	0	3	1	2	17
	>180	0	0	0	0	0	0	11	9	6	9	30	57

Table 2: One-way travel time to forest residues (thousand bone dry tons per year) from two different locations – Astoria, OR and Tillamook, OR.

Conclusions

In order for forest biomass residues to provide energy in a cost-effective manner, careful planning is necessary to ensure costs are minimized. Costs are dependent on a variety of factors, so analysis is necessary when considering construction of a biomass powered plant. Biomass plants are most cost effective when residual heat is used for drying lumber, and mill residues (such as bark) are used as supplemental fuel source.

There are still issues with the models that may be addressed in the future. When applied to steeper terrain, the transportation model tends to sometimes underestimate time. This is because the model treats all roads the same, and will sometimes prefer shorter distances with much steeper grades over longer distances with more gradual slopes. Future improvements to the model may include integrating a Digital Elevation Model (DEM) into the map. With this additional information, travel time could be more accurately modeled and the most time effective route identified.

References

ESRI Inc. ArcGIS 9.3. Redlands, CA. (1999-2009).

Lord, R., C. Ehlen, D. Stewart-Smith, John Martin, L. Kellogg, C. Davis, M. Stidham, M. Penner and J. Bowyer. 2006. *Biomass Energy and Biofuels from Oregon's Forests.* Prepared for Oregon Forest Resources Institute.

USDA. LEMMA Downloadable dataset – available at http://www.fsl.orst.edu/lemma [accessed 14 May 2010].

USDI. GTRN Downloadable GIS dataset – available at http://www.blm.gov/or/gis/data.php [accessed 14 May 2010].

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Consequences of Mill Closures, Parcelization, and Wood-to-Energy Expansion for the U.S. South's Wood Supply Chain

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Abstract -- The U.S. South's wood supply chain has lost 30% of its sawmills and nearly 20% of its pulpmills since the 1990s. At the same time, the South experienced population pressures that led to parcelization of timber tracts and reduced harvest tract sizes. Today, the wood-energy market is gaining traction and may provide a substantial market for wood fiber in the future. We conducted a survey of consulting foresters to determine how mill closures and changes in land ownership have impacted southern forestry and how consulting foresters expect the wood-energy market to impact landowners, mills, and foresters. Our findings suggest that inadequate timber markets exist at present because of an increase in timber supply and reduced forest products industry capacity. Ninety-four percent of respondents have observed mill closures or capacity reductions in their area and 91% of respondents believe that mill closures have negatively impacted the profitability of their timber sales. Fifty-five percent of respondents have observed an expansion of the wood-energy market in their state; and while only 12% of respondents have sold timber to a wood-energy facility, 98% of respondents suggested their clients are willing to do so. Ninety-five percent of responding foresters reported an average harvest tract size over 40 acres in 1999, while only 47% of respondents expected an average harvest tract size of more than 40 acres in 2019. Our findings suggest that the southern wood supply chain is in position to profit from a vibrant wood-energy market; however, reduced forest products industry capacity and parcelization are areas of concern for the southern wood supply chain.

Introduction

The southern wood supply chain has undergone substantial changes over the past two decades as forestland has changed hands, harvesting contractors have increased mechanization, and the forest products industry has increased capacity in some sectors and reduced it in others. Today, the wood-energy market is emerging as a new member of the southern wood supply chain and it is likely to impact traditional wood supply chain members (Bowyer 2008).

Thirty-three states have enacted renewable portfolio standards or goals which mandate utilities to produce a certain amount or percentage of electricity from renewable sources by a target date (Database of State Incentives for Renewable Energy 2010). Currently, only three southern states, North Carolina, Texas, and Virginia have renewable portfolio goals or standards. However, all southern states have financial incentives promoting bioenergy (Alavalapati et al. 2009).

There is concern among some members of the southern wood supply chain that wood-energy companies will compete for wood with the forest products industry. Perlack et al. (2005) suggested that currently non-commercial wood will be used for energy; however, they acknowledged that high energy prices and low pulpwood prices may allow pulpwood-sized material to be used for energy. Others suggest that competition between energy companies and mills will increase the price of pulpwood, making it prohibitively expensive for energy use (La Capra Associates 2006). Galik et al. (2009) suggested that wood-energy demand beyond a threshold level will put upward pressure on pulpwood prices. However, Conrad and Bolding (in press) found that state regulations and the absence of biofuel refineries greatly reduce the likelihood of competition between energy companies and forest products companies in Virginia, at least in the short term.

The southern pulp and paper industry has closed 17% of its mills and reduced production by 10% since the mid 1990s (Johnson et al. 2008, Johnson and Steppleton 2008). Likewise, the number of southern sawmills has declined by 60% since the 1970s and by 30% since 1995, although sawtimber production actually increased by 6% between 1995 and 2005 (Johnson et al. 2008). Between 1998 and 2004 real softwood pulpwood prices declined as hardwood pulpwood, hardwood sawtimber, and softwood sawtimber prices all failed to increase. Wear et al. (2007) attributed these trends to an increase in timber supply coupled with a decrease in demand.

The Southern Forest Resource Assessment stated that urbanization will have a larger impact on the health and extent of southern forests than any other factor (Wear and Greis 2002). Between 2000 and 2050 each southern state, with the exception of Oklahoma, is expected to convert more than 100,000 acres of forestland to other uses (Nowak and Walton 2005). Increasing urbanization can cause both a decrease in long term timber supply as forestland is taken out of production and also a decrease in short term supply as land clearing activities fail to offset reductions in silvicultural treatments (Barlow et al. 1998). Furthermore, as average tract size decreases, per ton logging costs rise because of more frequent moves (Moldenhauer and Bolding 2009, Cubbage 1983).

It is clear that the southern wood supply chain is in a state of change. However, it is uncertain how these changes will impact the competitiveness and profitability of the southern wood supply chain. The objectives of this study were to: (1 investigate consulting foresters expectations for and experiences with wood-based energy, 2) investigate the impact of mill closures and capacity reductions on the profitability of timber sales, and 3) examine how average harvest tract size has changed between 1999 and 2009 and how it is expected to change between 2009 and 2019.

Methods

A survey of consulting foresters was conducted during the summer of 2009 to investigate how wood-energy expansion, mill closure, and parcelization have and will impact the southern wood supply chain. Consulting foresters were chosen for this study because they interact with landowners, loggers, and forest products firms on a regular basis. In addition, because nearly 90% of southern forestland is privately owned (Butler 2008), consulting foresters have the potential to be involved in a significant proportion of forest management decisions.

Survey participants were selected from the membership list of the Association of Consulting Foresters (ACF) that is available on the ACF website. One representative was selected from each consulting firm listed in the states of Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia. If consulting firms listed multiple foresters, we selected the highest ranking member with an email address. For firms listed in multiple states, one representative from each state was included in the survey. Twelve firms did not provide an email address, and therefore were excluded from the study. The total sample size for the study was 254.

The survey was administered using survey.vt.edu. During mid-summer 2009 survey participants were mailed a pre-notice letter notifying them that they would receive a questionnaire via email. Approximately one week after the pre-notice letter we emailed respondents a link to the survey. Two additional emails were sent over the following two weeks that requested non-respondents to complete the questionnaire.

The questionnaire consisted of thirty multiple choice questions. Ten questions utilized a 5-point Likert scale (1 = strongly agree, 2 = agree, 3 = neutral, 4 = disagree, 5 = strongly disagree) with the remainder of the questions requesting categorical data. The two-tailed t-test was used to analyze Likert scale questions to test the null hypothesis that the mean response was neutral versus the alternative that the mean was different from neutral. Two-tailed, two sample t-tests assuming unequal variance were used to test whether or not mean responses from states with renewable portfolio standards were equal to mean responses from states without these regulations. Analysis of variance and the Tukey HSD test were used to determine whether or not statistically significant differences existed between the responses of foresters from the Atlantic Coast states (FL, GA, NC, SC, VA), Gulf Coast states (AL, LA, MS, TX), and Interior states (AR, KY, OK, TN). The chi-square test of independence was used to analyze nominal survey data.

Non-response bias was found to be insignificant using wave analysis (Armstron and Overton 1977), which compared the responses of the first thirty participants to the last thirty participants on four questions. The chi-square test ($\alpha = 0.05$) was used to test non-response bias because of the small sample size and the categorical nature of some of the data.

Results and Discussion

Eight emails were undeliverable, which reduced our sample size to 246. A total of 163 questionnaires were completed, which yielded an adjusted response rate of 66.3%.

Wood-Energy Expansion

Only 55% of respondents observed an expansion of wood-based energy in their state. Surprisingly, only 49% of foresters from states with renewable portfolio standards noticed an expansion of wood-based energy compared to 56% of foresters from other states. No statistically significant differences were observed between states with and without renewable portfolio standards for any question. Sixty-two percent of responding foresters from the Gulf Coast states observed an expanded wood-energy market compared to 54% of respondents from the Atlantic

Coast states and only 38% from the Interior states; however, these differences were not significant ($\chi^2 = 3.8$; P = 0.15).

Only 12% of respondents reported having sold timber to an energy facility (Figure 1). Seventeen percent of respondents from the Atlantic Coast states reported that their clients had sold wood to an energy facility compared to 9% from the Gulf Coast states, and no responding foresters from the Interior states had sold timber to an energy facility. These differences were statistically significant ($\chi^2 = 7.0$; P = 0.03). All respondents that had sold timber to an energy facility were satisfied with the transaction. This is a positive sign because a study in Sweden found that 15% of landowners who had sold wood to an energy facility were very negative about the experience and refused to sell timber to an energy facility again, probably because of concerns about soil fertility (Bohlin and Roos 2002).

Although a small percentage of respondents reported having sold timber to an energy facility, nearly all respondents suggested their clients would sell timber to an energy facility if a competitive price were offered (Figure 1). More than 80% of respondents expected the wood-energy market to improve the profitability of timberland. This suggests that if and when wood-energy markets become available, southern private landowners are willing to supply timber to the new market.

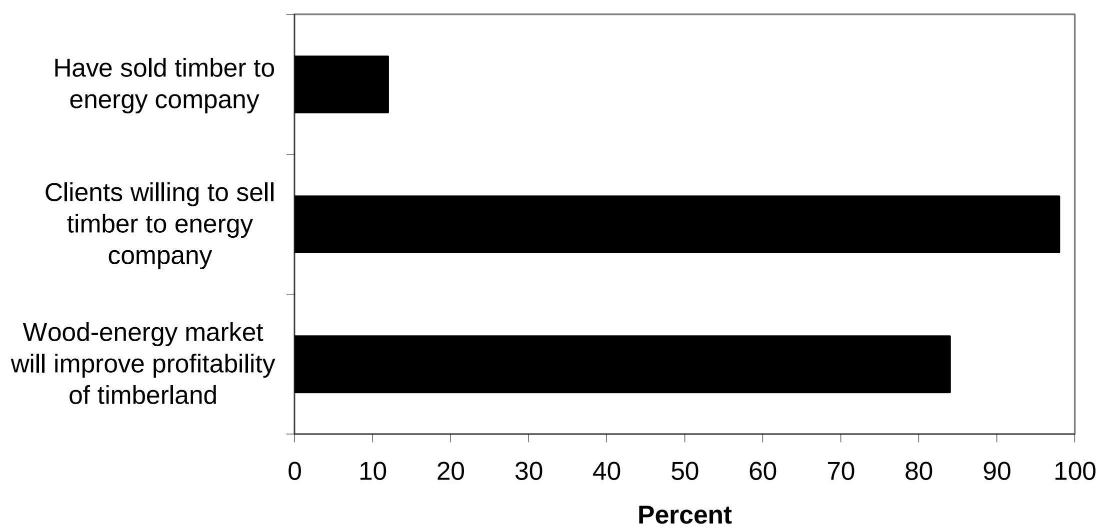

Figure 1: Consulting foresters experiences with and expectations for wood-based energy.

Two-thirds of respondents suggested that wood-energy firms will compete for wood with forest industry mills (Table 1). Only 10% of respondents expected energy facilities to have an advantage over forest industry mills if the two compete for timber, although a majority of respondents expected competition between mills and energy facilities to raise stumpage prices. These findings are consistent with past research that suggests wood-energy demand beyond a certain level will result in competition between energy facilities and the pulp and paper industry, thereby raising timber prices (Benjamin et al. 2009, Galik et al. 2009).

Table 1: Consulting foresters' opinions regarding the impact of wood-based energy on the southern wood supply chain. T-tests were conducted to test the hypothesis that the mean response to Likert scale questions (1 = strongly agree; 2 = agree; 3 = neutral; 4 =disagree; 5 = strongly disagree) was neutral ($\bar{x}$ = 3).

Question/Statement	Atlantic Coast	Gulf Coast	Interior	Overall
Wood-to-energy facilities will compete for wood with forest industry mills. (percent)				
Agree	63	74	54	66
Disagree	20	13	25	18
Neutral/Not Sure	16	13	21	16
Mean ($t = -6.84$; $P < 0.001$)	2.53	2.69	2.20	2.45
Competition between wood-to-energy facilities and forest industry mills will cause stumpage prices to increase. (percent)				
Agree	59	58	62	60
Disagree	10	15	14	12
Neutral/Not Sure	30	27	24	28
Mean ($t = -8.47$; $P < 0.001$)	2.44	2.49	2.35	2.44
If wood-to-energy facilities and forest industry mills compete for wood, who will have the advantage? (percent)				
Mills	27	27	32	28
Energy Facilities	14	9	10	10
Equal	28	24	29	27
Neutral/Not Sure	32	40	29	34

Mill Closure

Ninety-four percent of respondents reported mill closures in their area. Ninety-seven percent of respondents reported that sawmills in their area have closed or reduced capacity. Similarly, 64% of respondents reported shutdowns or capacity reductions at pulpmills, 63% at plywood/veneer mills, 62% at composite mills, and 2% reported shutdowns or reductions at wood pellet mills. A greater percentage of foresters in the Gulf Coast region (84%), had observed closures or capacity reductions at pulpmills than foresters in the Atlantic Coast (56%) and Interior regions (48%). These differences were significant ($\chi^2 = 20.8$; $P < 0.001$). Similarly, a greater percentage of respondents from the Gulf Coast (85%) observed closures or reductions at plywood/veneer mills than Atlantic (53%) and Interior states (45%), and these differences were statistically significant ($\chi^2 = 20.8$; $P < 0.001$).

More than 90% of respondents reported that mill closures had reduced the profitability of timber sales and this response was significantly different from neutral ($T = -23.5$; $P < 0.001$) (Figure 2). Foresters from the Interior states were most adamant that mill closure had reduced the profitability of their timber sales ($P < 0.05$). Seventy-one percent of respondents believe that timber markets are inadequate and this response was significantly different from neutral ($T = 9.6$; $P < 0.001$).

Mill closures have been reported by several previous studies (Bowe et al. 2001, Spelter et al. 2007, Johnson et al. 2008). This study confirms that mill closures have had a negative impact on timber sale profitability.

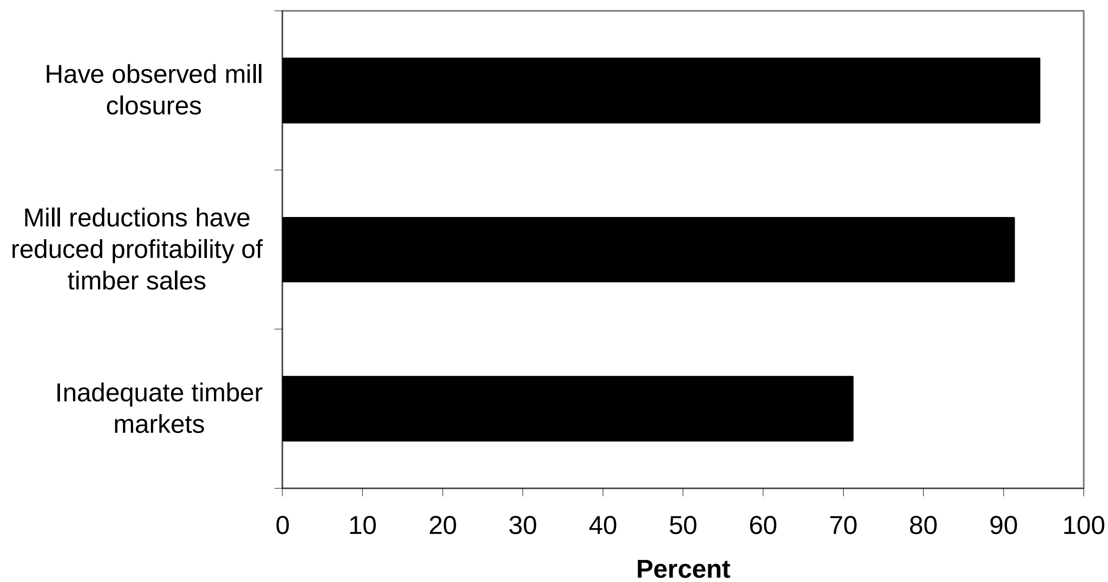

Figure 2: Consulting foresters’ observations of mill closures and their impact on timber sale profitability.

Average Harvest Tract Size

Respondents reported that the average harvest tract size declined across the southeast between 1999 and 2009, and this trend is expected to continue between 2009 and 2019 (Table 2). Ninety-five percent of respondents reported an average harvest tract size greater than forty acres in 1999, compared to 70% in 2009, and less than half of respondents expect an average harvest tract size greater than forty acres in 2019. Likewise, the percentage of respondents reporting an average tract size over 80 acres declined from 41% to 14% between 1999 and 2009.

During each time period, a greater percentage of Gulf Coast respondents reported an average harvest tract size over 40 acres compared to respondents from the Atlantic Coast and Interior states (Table 2). The Atlantic Coast states had the largest shift towards smaller tract sizes between 1999 and 2009 and respondents from these states expected a further shift over the next decade as well.

Table 2: Average harvest tract size in the U.S. South in 1999, 2009, and 2019 (projected) as reported by consulting foresters from the Atlantic Coast, Gulf Coast, and Interior States. Responses are reported as the percentage of respondents who reported or predicted a particular average harvest tract size.

Time Period	Region	Average Harvest Tract Size				
		(10ac)	(10-19ac)	(20-39ac)	(40-80ac)	(80ac)
1999	Atlantic Coast	0	0	9	58	33
	Gulf Coast	0	0	0	40	60
	Interior	0	4	4	68	25
	U.S. South	0	<1	5	54	41
2009	Atlantic Coast	0	4	43	46	8
	Gulf Coast	0	0	4	74	23
	Interior	0	7	25	54	14
	U.S. South	0	3	27	56	14
2019 projected	Atlantic Coast	1	12	58	26	3
	Gulf Coast	0	0	23	60	17
	Interior	0	18	39	25	18
	U.S. South	1	9	43	37	10

The decrease in average harvest tract size observed in this study corresponds with the findings of Moldenhauer and Bolding (2009). Reduced harvest tract size is of concern for consulting foresters because landowners with small holdings may be less likely to use a consultant to market their timber. Furthermore, for foresters who work on a commission basis, smaller tract sizes will result in decreased revenue from individual timber sales. Since foresters expect parcelization to continue, these issues are likely to be magnified in the future.

Conclusion

This study found that the southern wood supply chain is in position to benefit from an expanded wood-energy market. Nearly all respondents reported that their clients are willing to sell timber to energy facilities, and the majority of responding foresters expected the wood-energy market to improve the profitability of their clients' timberland investments. Furthermore, our finding that mill closures and capacity reductions have resulted in inadequate markets for timber suggests that wood is available for energy use without negatively impacting the forest products industry.

Finally, our finding that the average harvest tract size is declining is likely to have a negative impact on all members of the southern wood supply chain. For loggers, smaller tracts mean more frequent moves, which increase per ton logging costs. For foresters working on a commission basis, smaller tracts mean less profit from individual timber sales. Landowners may also see reduced stumpage prices on smaller tracts if mills are forced to pay loggers more per ton to compensate them for increased moving costs. Lastly, mills could also suffer from reduced harvest tract sizes if loggers require a higher cut and haul rate to compensate for moving costs, or if timber supply decreases because timberland conversion outpaces gains in productivity.

References

Alavalapati, J.R.R., A.W. Hodges, P. Lal, P. Dwivedi, M. Rahmani, L. Kaufer, J.R. Matta, A. Susaeta, S. Kukrety, and T.J. Stephens III. 2009. Bioenergy roadmap for southern United States. Southeast Agriculture and Forestry Energy Resources Alliance (SAFER), Southern Growth Policies Board, North Carolina. 130 p.

Armstron, J., and Overton, T. 1977. Estimating nonresponse bias in mail surveys. *Journal of Marketing Research* 14: 396-402.

Barlow, S.A., I.A. Munn, D.A. Cleaves, and D.L. Evans. 1998. The effect of urban sprawl on timber harvesting: A look at two southern states. *J. For.* 96(12): 10-14.

Benjamin, J., R.J. Lilieholm, and D. Damery. 2009. Challenges and opportunities for the northeastern forest bioindustry. *J. For.* 107(3): 125-131.

Bohlin, F. and A. Roos. 2002. Wood fuel supply as a function of forest owner preferences and managment styles. *Biomass and Bioenergy* 22: 237-249.

Bowe, S.A., R.L. Smith, and P.A. Araman. 2001. A national profile of the U.S. hardwood sawmill industry. *For. Prod. J.* 51(10): 25-31.

Bowyer, J.L. 2008. The GREEN movement and the forest products industry. *For. Prod. J.* 58 (7-8): 6-13.

Butler, B.J. 2008. *Family forest owners of the United States, 2006*. USDA Forest Service Gen. Tech. Rep. NRS-27. 72 p.

Conrad, J.L. IV, and M.C. Bolding. (In press). Virginia's woody biomass market: Opportunities and implications. Accepted for publication by the Southern Journal of Applied Forestry on August 14, 2009.

Cubbage, F. 1983. *Economics of forest tract size: Theory and literature.* USDA Forest Service General Technical Report SO-41. 21 p.

Database of State Incentives for Renewables and Efficiency. 2010. Available online at www.dsireusa.org/summarymaps/index.cfm?ee=1&RE=; last accessed Mar. 8, 2010.

Galik, C.S., R. Abt, and Y. Wu. 2009. Forest biomass supply in the southeastern United States—Implications for industrial roundwood and bioenergy production. *J. For.* 107(2): 69-77.

Johnson, T.G., J.W. Bentley, and M. Howell. 2008. *The South's timber industry—an assessment of timber product output and use, 2005.* USDA Forest Service Resource Bulletin SRS-135. 52 p.

Johnson, T.G. and C.D. Steppleton. 2008. *Southern pulpwood production, 2006.* USDA Forest Service Resource Bulletin SRS-134. 42 p.

La Capra Associates. 2006. *Analysis of a renewable portfolio standard for the state of North Carolina.* La Capra Associates, Boston, MA. 154 p.

Lundmark, R. 2006. Cost structure of and competition for forest-based biomass. *Scandinavian Journal of Forest Research* 21: 272-280.

Moldenhauer, M.C., and M.C. Bolding. 2009. Parcelization of South Carolina's private forestland: Loggers' reactions to a growing threat. *For. Prod. J.* 59(6): 37-43.

Nowak, D.J. and J.T. Walton. 2005. Projected urban growth 2000-2050 and its estimated impact on the US forest resource. *J. For.* 103(8): 383-389.

Perlack, R. D., L. L. Wright, A.F. Turhollow, R.L. Graham, B.J. Stokes, and D.C. Erbach. 2005. *Biomass as feedstock for a bioenergy and bioproducts industry: The technical feasibility of a billion-ton annual supply*. USDE and USDA. Oak Ridge National Laboratory. DOE/GO-102995-2135. 59 p.

Spelter, H., D. McKeever, and M. Alderman. 2007. *Profile 2007: Softwood sawmills in the United States and Canada.* USDA Forest Service Research Paper FPL-RP-644. 65 p.

Wear, D.N., D.R. Douglas, and J. Prestemon. 2007. *The U.S. South's timber sector in 2005: A prospective analysis of recent change.* USDA Forest Service Gen. Tech. Rep. SRS-99. 29 p.

Wear, D.N. and J.G. Greis. 2002. *Southern forest resource assessment: summary report.* USDA Forest Service Gen. Tech. Rep. SRS-54. 103 p.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Log Hauling Vehicle Accidents in the State of Georgia, 1988-2008

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ABSTRACT

Mechanical failure rates associated with logging vehicle accidents in Georgia are dramatically lower today than they were in 1988–1991 before these trucks became subject to random roadside inspections. Mechanical failure dropped by half for logging tractor-trailers (from 10.9% to 5.5%) and by three-fourths for logging trucks (from12.9% to 3.2%). Mechanical failure is now the fifth most cited contributing factor in logging tractor-trailer accidents instead of first as it was prior to 1991. Specific types of mechanical failures have also declined sharply. Three potential failure items that are visually checked during roadside inspections – brakes, slick tires, and lights – have seen the most dramatic declines. Brake failure has dropped by two-thirds and improper lights as a factor have almost disappeared. Factors associated with logging vehicle accidents today in Georgia closely resemble those associated with all trucking accidents generally.

INTRODUCTION

The U.S. forest products industry depends heavily on the trucking industry for transporting wood products. An overwhelming majority of raw forest products is transported via articulated 18-wheel tractor-trailers, and a very small percentage is moved via smaller straight-frame logging trucks. Roadway crashes are the leading cause of unintentional death and occupational fatalities in the United States. Tractor-trailer occupants accounted for 28 percent of all occupational fatalities from motor vehicle accidents between 1992 and 2000 (Pratt 2003). Previous research has attempted to isolate risk factors for large truck accidents (Jones and Stein 1989, Moses and Savage 1994, Braver et al. 1997, Lee-Jean and Cohen 1997), and the federal government performs separate analyses of accidents within this class of vehicle (Pratt 2003).

Loads of cut logs in route to forest products processing facilities often originate in remote locations and require traversing gravel roads, local and state paved roads, and possibly federal limited access highways. During the late 1980s, the safety of logging trucks was questioned in articles appearing in a number of Georgia newspapers (Earle 1987). The articles often quoted Georgia Department of Transportation (DOT) officials alleging that logging trucks were less safe than other trucks on Georgia highways. A negative public image issue emerged, leading to discussions within the forestry community. As a first step, the Georgia Forestry Association (GFA) and the University of Georgia (UGA) collaborated with forest industry to sponsor numerous Skilled Driver Workshops across the state that trained hundreds of logging truck drivers in how to operate their vehicles in a safe manner. In another effort, the UGA obtained funding from the Logging Safety Foundation (now Timber Harvesting and Transportation Safety

Foundation) and used it to obtain motor vehicle accident data from the state for 1988–1991. These data confirmed many of the accusations made by the Georgia DOT in the late 1980s (Greene and Jackson 1992). Mechanical failure was involved in 10.9 percent of logging tractor-trailer accidents and 12.9 percent of logging truck accidents compared to just 3.8 percent of other heavy truck accidents during these four years. A logging “tractor-trailer” is an articulated vehicle consisting of a tractor with an attached trailer that most often hauls tree-length stems or two bunks of random-length wood parallel to the frame. A “logging truck” is a straight-frame (non-articulated) truck that is equipped to handle short pulpwood loaded across the frame or longer lengths loaded parallel to the frame. Over 90 percent of wood moved in Georgia is in tree-length form on tractor-trailers (Baker and Greene 2007).

A Georgia law enacted in 1981 authorized the Public Service Commission to conduct random roadside safety inspections for trucks, but forestry and agriculture were allowed exemptions due to their political power in the state legislature. Faced with these trucking accident statistics and the resulting negative public image issue, the forestry community began to lobby to have the exemption for forest products trucks removed. On July 1, 1991, logging vehicles with a gross vehicle weight rating (GVWR) of 44,000 or more became subject to inspections under the Georgia Forest Products Trucking Act (Georgia 2006).

Additionally, the federal government also stiffened driver-training requirements with the adoption of the Federal Commercial Drivers License that took effect on April 1, 1992, and mandatory drug testing of all heavy truck drivers had taken effect earlier that year. The forestry community was hopeful that the combined effect of the state and federal efforts would result in a significant reduction in logging truck accidents.

UGA continued to obtain these accident records with funding from GFA and the Timber Harvesting & Transportation Safety Foundation and annually updated this database through 2004. A comparison of accident factors during the pre-regulation period of 1988–1991 with a 3-year post-regulation period (1992–1994) found that mechanical failure as a contributing factor fell significantly (Greene et al. 1996, Greene 1996). Motor vehicle accident data for the 10-year period 1995–2004 were compared with previous years and found that the percentage of logging-related trucking accidents and mechanical failure rates continued to decline (Greene et al. 2007). This was attributed to both the stiffer regulatory requirements as well as the training effort undertaken to prepare for compliance with these new guidelines.

Motor vehicle accident data for the 4-year period 2005–2008 were obtained with funding from the Southeastern Wood Producers Association to see if the reduction in mechanical failures associated with log truck accidents immediately after the passage of this legislation persisted through today.

METHODS

Law enforcement officers who investigate highway accidents record these data for each accident occurring on Georgia’s roadways. Selecting from a list of 26 factors on the form, the officer can indicate which factors contributed to the accident. The officer’s judgment is based upon their personal observations and eyewitness accounts. There is neither a minimum or maximum number of factors that can or must be selected. The Georgia Department of Motor Vehicle Safety maintains a computerized database of this information. This form (DPS-523) was changed in 1994, retaining the types of information recorded before 1994 and adding more detail in some areas. Prior to analysis for this study, the accident data through 2008 were obtained to update the existing accident record tables. This provided a complete record of truck accident statistics in Georgia for the time period of 1988–2008 that could be used to identify trends in accident factors and to compare factors associated with accidents before regulation (1988–1991) to those immediately following regulation implementation and the years after regulations were enacted.

RESULTS AND DISCUSSION

Logging vehicles comprise a smaller share of the total accident pool today than 20 years ago. The percentage of truck accidents that involved logging vehicles has declined slightly since the late 1980s (Table 1). Logging tractor-trailers and logging trucks accounted for 3.7 percent and 1.8 percent of all truck accidents in the state during the years 1988–1991. For the most recent 4-year period, they accounted for 2.9 percent and 0.9 percent of truck accidents, respectively. There were minimal percentage changes from 2001-2004 to 2005-2008. Though the total number of accidents increased substantially between the two earlier time periods for logging tractor-trailers and logging trucks, there was a slight decline in the 2005-2008 time period. The number of logging trucks dropped sharply with the decline of shortwood markets in the southern United States. For example, unpublished data from a 2007 survey of Georgia's logging population showed that 27 logging trucks were owned among the respondent logging firms compared to 560 logging tractor-trailers, or 1 for every 20.7 tractor-trailers (UGA 2007). Ten years earlier the same survey found 474 tractor-trailers and 85 logging trucks among the respondent logging firms, or 1 truck for every 5.6 tractor-trailers (UGA 1997). Increases in other heavy truck traffic at rates faster than logging vehicles would also serve to help lower these percentages.

Table 1. *Percentage and number of truck accidents in Georgia by truck type, 1988-1991, 2001-2004, and 2005-2008.*

Type of Truck	1988-1991		2001-2004		2005-2008	
	% of Accidents	No. of Accidents	% of Accidents	No. of Accidents	% of Accidents	No. of Accidents
Logging tractor-trailer	3.7%	1,199	3.1%	2,629	2.9%	2,556
Logging truck	1.8%	567	1.0%	863	0.9%	808
Other heavy trucks	94.5%	30,550	95.9%	82,103	96.1%	83,533

During the years 1988–1991 before truck inspections, mechanical failure was cited in 10.9 percent of logging tractor-trailer accidents and 12.9 percent of logging truck accidents (Table 2). These rates fell to 4.8 percent and 4.2 percent, respectively in the 2001-2004 time period, and continued to fall for logging trucks to 3.2 percent for the most recent period. There was a slight increase to 5.5 percent for logging tractor-trailers in the 2005-2008 period. There was a sharp rate of decline in mechanical failure following state and federal regulatory changes in the early 1990s, but the overall decline has been slow and steady for the past twelve years (Fig. 1).

Logging trucks exhibited a slower initial decrease than logging tractor-trailers, as they were not subject to the regulations passed in 1992, but the mechanical failure rate has continued to decline slightly. By comparison, the mechanical failure rates for other heavy trucks fell from 3.8 percent to 2.3 percent during this time period. Given the much harsher operating environment for logging vehicles, the difference between these classes of vehicles are relatively small and somewhat expected. The industry should be encouraged by the significant early—and seemingly lasting—improvements obtained, while continuing to focus on obtaining further improvements in this record.

Table 2. *Frequency of mechanical failure cited as a contributing factor in truck accidents in Georgia by truck type during 1988–1991 compared to 2005–2008.*

Type of Truck	1988-91	2001-04	2005-08
	-----------------------------(%)---------------------------------		
Logging Tractor-Trailers	10.9	4.8	5.5
Logging Trucks	12.9	4.2	3.2
Other Heavy Trucks	3.8	2.5	2.3

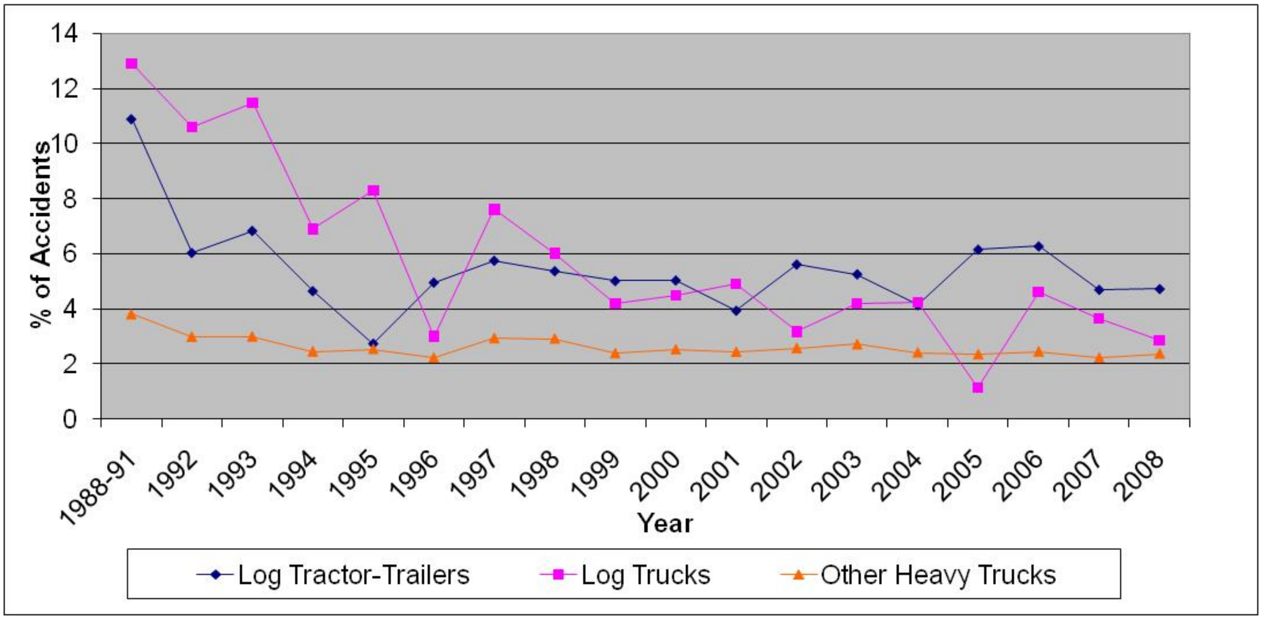

Figure 1. *Accident rates due to mechanical failure from 1988-1991 to 2008.*

Accidents that involved logging tractor-trailers were of greatest interest since they haul the majority of wood in Georgia. Not only has the mechanical failure rate for these trucks fallen by half over the past 20 years (Table 2), it also dropped from being the most cited contributing factor to the fifth most cited factor since 1991, but down from seven since the last period (Table 3). The factors associated with logging tractor-trailer accidents now closely mirror those involved with other heavy truck accidents.

Table 3. *Most cited contributing factors in accidents involving logging tractor-trailers in Georgia during 1988–1991 compared to 2005–2008 (# = rank, 1 = most cited).*

Contributing Factor	1988-1991	2001-2004	2005-2008
Mechanical Failure	1	7	5
Misjudged Clearance	2	3	3
Too Fast for Conditions	3	6	4
Failed to Yield	4	5	6
Following Too Close	5	1	1
Driver Lost Control	6	2	2
Improper Turn	7		
Improper Lane Change		4	7

Mechanical failure is not only listed in the list of contributing factors on the accident form, but specific mechanical failures may be indicated by the officer working the accident to help pinpoint the type of failure. Five failures are listed: tire failure, slick tires, brake failure, improper lights, and steering failure. The observed frequency of each of these factors associated with logging vehicle accidents dropped, in many cases dramatically, between 1988–1991 and 2008 (Figures 2-6 and Table 4).

Table 4. *Mechanical failure rates as a percent of all accidents by type of truck and failure type for three periods.*

Variable	Truck Type	1988-1991	2001-2004	2005-2008
Tire failure (%)	Logging tractor-trailer	1.18	0.81	0.86
	Logging truck	1.47	0.73	0.62
	Other heavy trucks	0.62	0.75	0.77
Slick tires (%)	Logging tractor-trailer	3.46	1.28	0.82
	Logging truck	3.50	1.36	0.99
	Other heavy trucks	0.27	0.25	0.14
Brake failure (%)	Logging tractor-trailer	6.51	1.62	2.19
	Logging truck	7.50	2.32	1.49
	Other heavy trucks	1.69	0.91	0.78
Improper lights (%)	Logging tractor-trailer	2.05	0.41	0.23
	Logging truck	3.10	0.0	0.12
	Other heavy trucks	0.23	0.10	0.08
Steering failure (%)	Logging tractor-trailer	0.59	0.17	0.12
	Logging truck	0.42	0.37	0.37
	Other heavy trucks	0.12	0.10	0.11

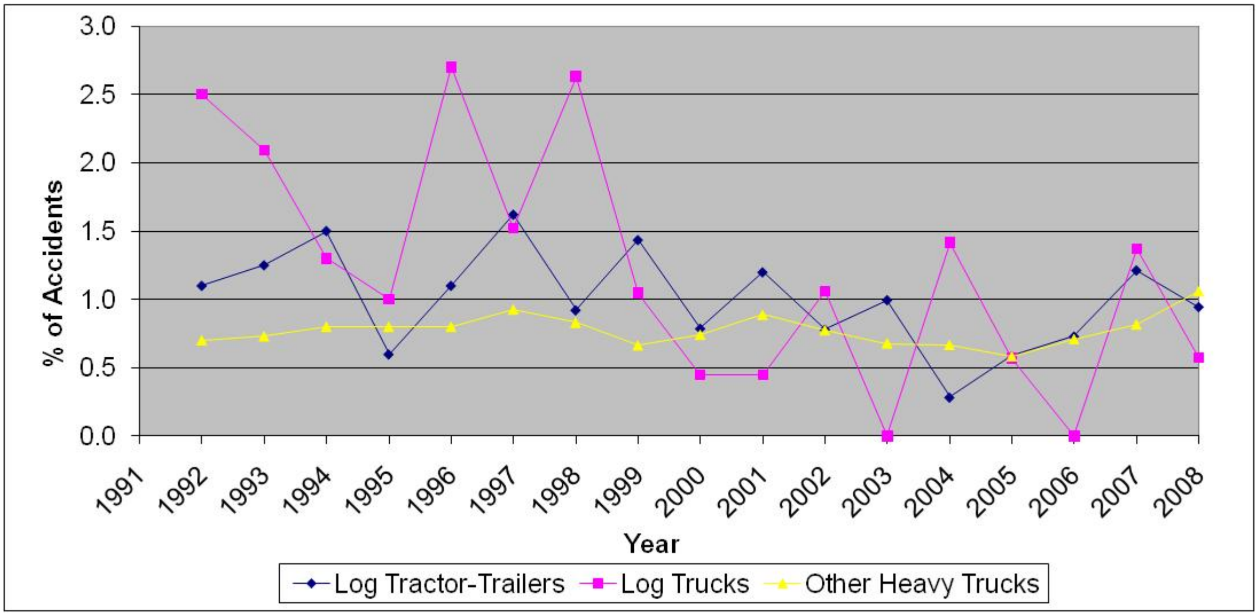

Figure 2. *Accident rates due to tire failure from 1991 to 2008.*

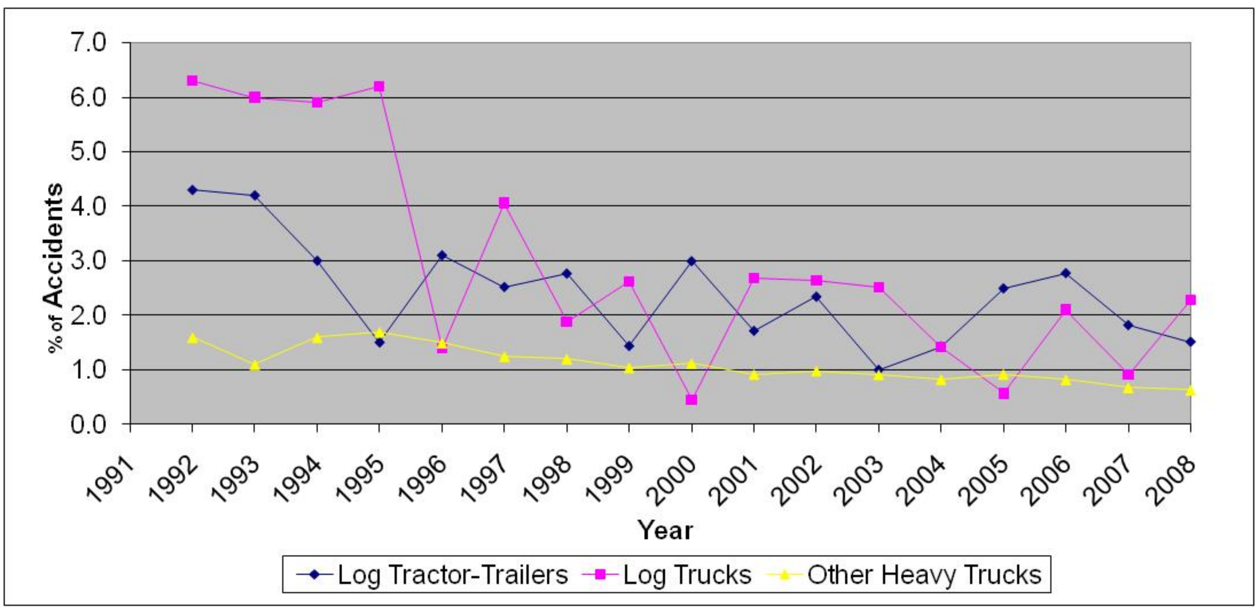

Figure 3. *Accident rates due to brake failure from 1991 to 2008.*

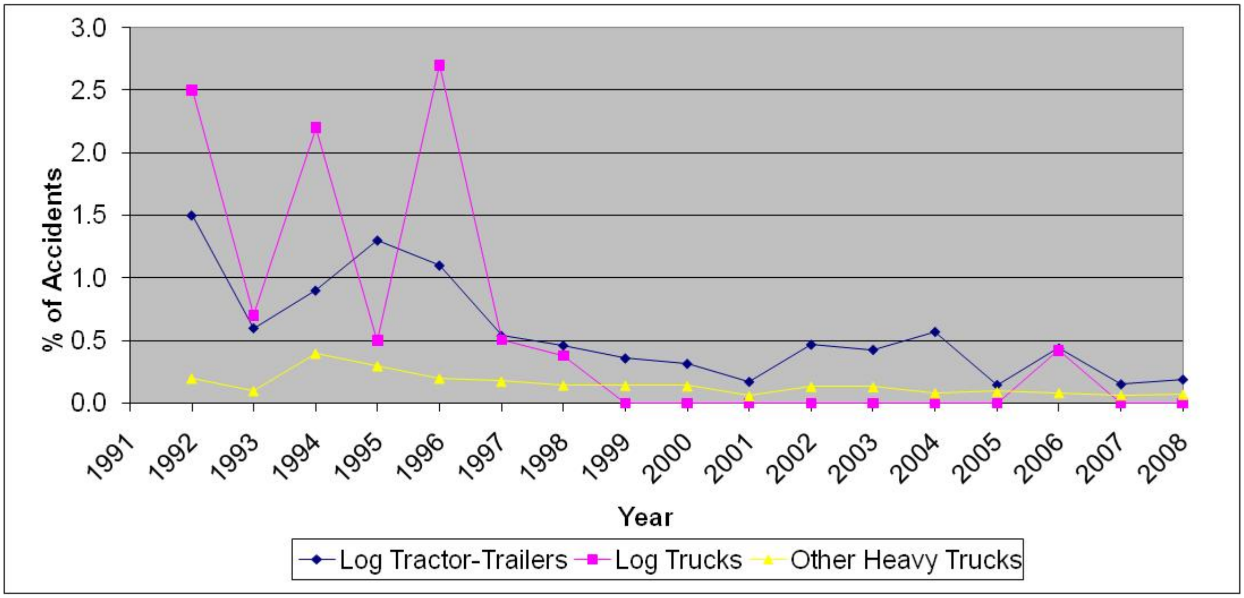

Figure 4. *Accident rates due to improper lights from 1991 to 2008.*

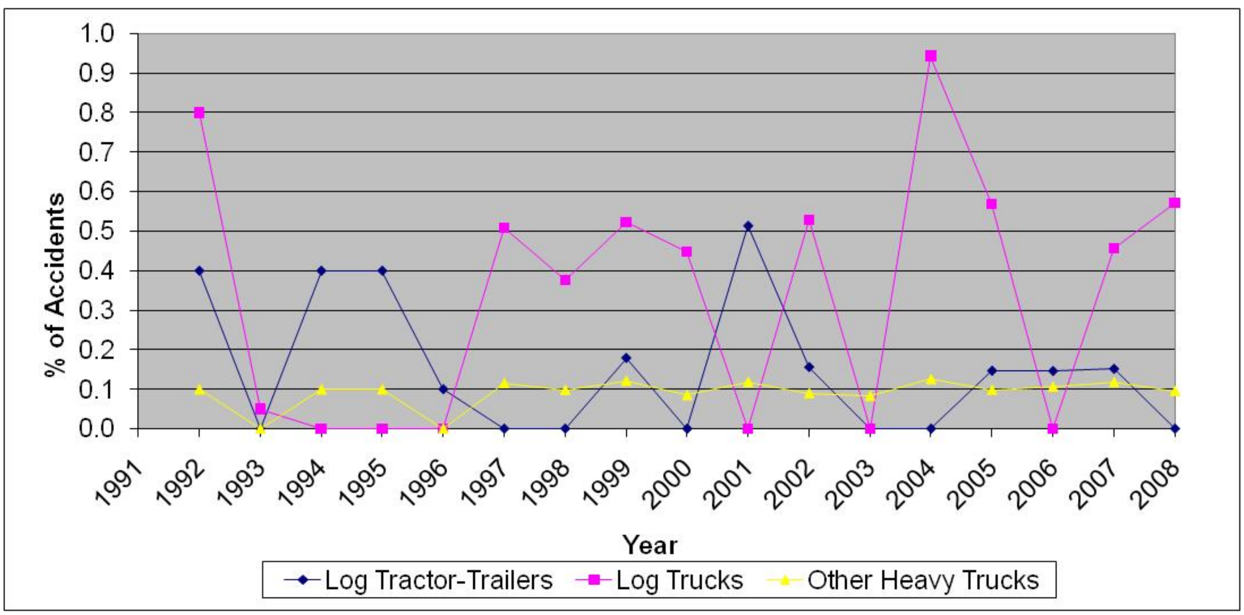

Figure 5. *Accident rates due to steering failure from 1991 to 2008.*

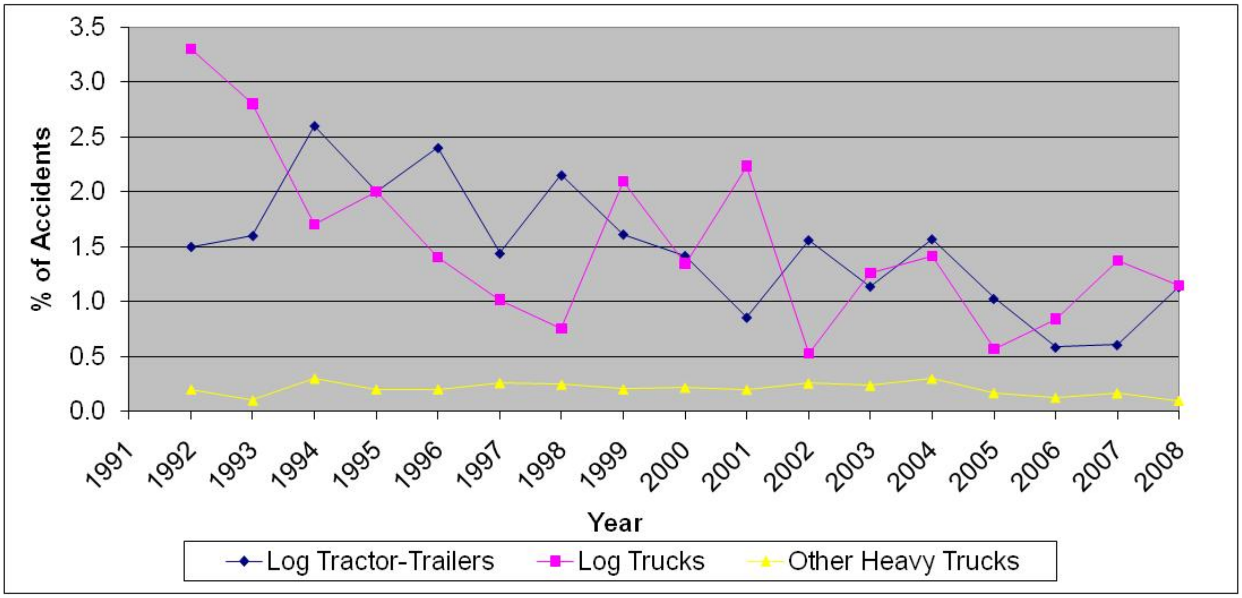

Figure 6. *Accident rates due to slick tires from 1991 to 2008.*

Tire failure dropped slightly for logging tractor-trailers and by two-thirds for logging trucks since 1991 (Table 4). The rate of tire failure increased slightly for other heavy trucks. The most dramatic improvement for logging vehicles was the reduction in slick tires as a causal agent. For both logging tractor-trailers and logging trucks, slick tires as a factor in accidents dropped by two-thirds from approximately 3.5 percent of accidents to 0.82 percent and 0.99 percent, respectively, over the 20-year period. Visual inspection of tire tread is a key component of the random safety inspections that started in 1991. Slick tires associated with accidents of other heavy trucks occurred half as often in 2008 than in 1988-1991, and the failure rates for slick tires in other heavy trucks are still lower than for all classes of logging vehicles.

Brake failure as a contributing factor in accidents continues to be much lower today than in 1991 (Table 4). Before 1991, brake failure was a factor in 6.51 percent and 7.50 percent of accidents involving logging tractor-trailers and logging trucks, respectively, compared to a brake failure rate of just 1.69 percent for other heavy trucks before 1991. Logging vehicles travel far shorter routes and spent more time on single-lane and two-lane roads than many of the trucks found in the “other heavy truck” category that are long-haul trucks spending long hours on multi-lane roads with much less frequent braking. Braking is more frequent and likely necessary with less warning for logging vehicles. Brake condition is also a key visual inspection point in the roadside safety inspections performed on Georgia logging vehicles. Today, brake failure is a factor in just 2.19 percent of logging tractor-trailer accidents compared to about 0.78 percent of other heavy truck accidents. Given the differences in the working environments of these categories of vehicles, this seems to be a reasonable difference.

Another visual inspection point involves proper working lights on vehicles (Table 4). Prior to 1991, improper lights were cited in 2.05 percent of logging tractor-trailer accidents and in 3.10 percent of logging truck accidents. During this same time period, improper lights were cited in only 0.23 percent of other heavy truck accidents. Today, improper lights are cited in just

0.23 percent of logging tractor-trailer accidents, in 0.12 percent logging truck accidents, and are involved in just 0.08 percent of heavy truck accidents. These improvements are undoubtedly due to greater inspection with logging vehicles, but more reliable lighting systems may also help account for this record. Steering failure has never been a significant factor in truck accidents, of any type, in Georgia (Table 4).

CONCLUSIONS

Trucks that haul forest products in Georgia today have accidents statistics that in most cases resemble very closely those of other heavy trucks. This is due to regulatory changes and driver education programs implemented in the early 1990s. Factors associated with logging truck accidents so closely mirror those of heavy trucks generally that future education efforts should focus primarily on general, rather than industry-specific, trucking issues.

While accident statistics for logging vehicles have improved significantly, they are still higher than for the heavy truck population generally – perhaps due to the operating environment – therefore ongoing vigilance and education are required to maintain and further improve the safety record of the log trucking community.

ACKNOWLEDGEMENTS

The authors thank the Southeastern Wood Producers Association for their financial support of this research and Angie Rios for her efforts in compiling and updating the data used in these analyses.

LITERATURE CITED

Baker, S.A. and W.D. Greene. 2007. Georgia logger survey. Presentation to Southern Region Council on Forest Engineering meeting, Hot Springs, AR. April 24.

Braver, E.R., P.L. Zador, D. Thum, E.L. Mitter, H.M. Baum, and F.J. Vilardo. 1997. Tractor-trailer crashes in Indiana: A case-control study of the role of truck configuration. Accident Analysis and Prevention. 29(1): 79-96.

Earle, J. 1987. Logging trucks a safety problem, state officials say. Atlanta J. Constitution. 9 March, p. 3(E).

Georgia. 2006. Georgia Forest Products Trucking Rules. Official Code of Georgia Annotated Sec. 46-1-1.

Greene, W.D., S.A. Baker, and T. Lowrimore. 2007. Analysis of log hauling vehicle accidents in the state of Georgia, USA, 1988–2004. International Journal of Forest Engineering ,18(2): 52-57.

___________. 1996. Mechanical failure rate of logging tractor-trailers in Georgia. Technical Release 96-R-51. American Pulpwood Association, Inc. Rockville, MD. 2 p.

___________ and B.D. Jackson. 1992. Georgia logging vehicle monitoring system. Technical Release 92-R-68. American Pulpwood Association, Inc. Washington, DC. 2 p.

____________, B.D. Jackson, L. Shackleford, R.L. Izlar, and W. Dover. 1996. Safety of log transportation after regulation and training in the State of Georgia, USA. J. of Forest Engineering. 7(3): 25-31.

Jones, I.S. and H.S. Stein. 1989. Defective equipment and tractor-trailer crash involvement. Accident Analysis and Prevention. 21(5): 469-81.

Lee-Jean, L. and H.H. Cohen. 1997. Accidents in the trucking industry. International J. of Industrial Ergonomics. 20: 287-300.

Moses, L.N. and I. Savage. 1994. The effect of firm characteristics on truck accidents. Accident Analysis and Prevention. 26(2): 173-79.

Pratt S. 2003. Work-related roadway crashes. Challenges and opportunities for prevention, in NIOSH Hazard Review. 2003, Dept. of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health. Cincinnati, OH. 92 p.

University of Georgia (UGA). 2007. Unpublished data from 2007 Georgia logging contractor survey.

___________. 1997. Unpublished data from 1997 Georgia logging contractor survey.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Hearing Threshold Shift of Loggers Exposed to Long-term Noise

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Problem

- Occupational noise exposure is a primary factor in permanent hearing loss.
- This study attempts to determine whether long term hearing loss in loggers is associated with noise emitted by logging equipment.

Abstract

To evaluate hearing loss, the hearing capacity of each participant was measured by the obtaining the lowest possible hearing (in decibels) needed to hear a pure tone signal at predetermined frequencies. The participants were 26 male forestry workers (loggers aged 20 through 59) who are directly involved with the operation of logging equipment. The equipment includes chainsaws, loaders, skidders and cutters.

There was a significant increase in hearing threshold in the participant population, as compared to a normal population. Furthermore, at 4000 Hz, the mean hearing threshold of the participants was significantly higher than at the rest of the frequencies. The hearing threshold shifts at 1000, 2000 and 4000 Hz were 4.9, 9.5 and 18.0 dB respectively. Hearing threshold shifts of 50 to 59 year olds was significantly higher than of 20 to 29 year olds by a 13 dB difference. A significant decrease in the hearing threshold (of 3.4 dB) was found between those participants who wore hearing protection and those who did not. A significant decrease in the hearing threshold shift was found in experience groups 1 (1 to 10 yrs of experience) and 3 (21 to 30 yrs of experience) between those participants who wore hearing protection and those who did not.

Literature Review

Type of Industry, Work, or Activity	Noise Levels (dB)	Source
Insulation Workers	78	Neitzel and Seixas (2005)
Masonry Workers	81	Neitzel and Seixas (2005)
Electricians	81	Neitzel and Seixas (2005)
Sheet Metal Workers	81	Neitzel and Seixas (2005)
Ironworkers	83	Neitzel and Seixas (2005)
Plumbers (Welding Confined)	90	Chambers, R.M. *et. al.* (1989)
Wood and Furniture Industry	90	Vinzents and Laursen (1993)
Foundry Industry	91	Daniell W. *et. al.* (2002)
Farming	94	Yearout and Brown (1991)
Power Boating	95	Yearout and Brown (1991)
Wood Crafting	98	Yearout and Brown (1991)
Forest Loggers	**100**	**Taoda *et al.* (1987)**
Wood Pallet Manufacturing	104	Malkin *et. al.* (2005)
Drop Forging	108	Taylor et. al. (1984)
Drag Racing	120	Yearout and Brown (1991)

SPOT READINGS

Machine	Idle (dB)	Full throttle (dB)
Skidder 1997 Franklin Tree Farmer 170 (enclosed cab)	73	100
Skidder 1997 Caterpillar 515 (enclosed cab)	72	84
Skidder 1995 Caterpillar 518C	82	94
Skidder 1964 Franklin Tree Farmer C6	78	102
Skidder 1960 Franklin Tree Farmer C5	82	100
Cutter 1998 Tigercat 845	74	90 (not cutting)
Cutter 1996 Barko 885	76	96 (not cutting)
Loader 1998 Tigercat 860S	68	74
Loader 1998 Tigercat 860S with fan on		82
Loader 1998 Tigercat 860S with fan and radio on		90
Loader 1996 Barko 169B	78	92
Loader 1996 Prentice 210E	80	90
Loader 1960 Barko 160	90	108
Bulldozer 1997 Caterpillar D4H XL	98	102
Bulldozer 1976 John Deere 450 bulldozer	85	98 (¾ throttle)
Bulldozer 1964 Caterpillar D5	84	112
Chainsaw 2002 Stihl 026	80	110
Chainsaw 1994 Shindaiwa 757	85	115 – 120
Chainsaw 1984 Stihl 038	90	112

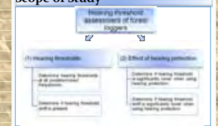
Source: de Hoop & Lalonde 2003, LSU AgCenter

Hearing Assessment Studies

Type of Industry, Work, or Activity	Hearing Thresholds (dB)	Source
Forest Workers	**42**	**Tunay & Melemez (2008)**
Hydro-electric Plant	32	Celik *et al.* (1998)
Farmers	36	Thelin *et al.* (1983)
Construction Industry	30	Hong (2005)
Aluminum Manufacturing	10 (STS)	Rabinowitz *et al.* (2006)
Lumber Mill	10 (STS)	Daivies *et al.* (2008)

Methodology

Scope of Study



Methods and Procedure

Participants:

- Twenty-six male(age=43.2±10.4) forest loggers participated in the experiment
- Audiometric testing was performed on all participants
- Results from experimental group were compared with OSHA (2008) age-corrected tables for hearing threshold.
  - To determine if the hearing threshold of forest loggers has increased or follows the same trend as the age-corrected tables.
- The participants were free from any kind of acute or chronic hearing loss due to any accident or illness.

Methods and Procedure

Experimental Design

- Independent Variables:
  - Frequencies of pure tone(125 Hz to 8000 Hz)
  - Age
  - Age groups
  - Experience groups
- Dependent Variables:
  - The sound level threshold (SLT) at each frequency.

Data Analysis

Normalizing data:

- Purpose is to compare data between participants disregarding age:

$$Obs_x = SLT_x - AT_y$$

- AT_y = Hearing threshold from age corrected tables (OSHA, 2008)

Results

Results – Hearing Threshold

- Average hearing threshold was 17.7 dB

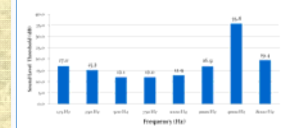


Figure 1: Hearing threshold for all frequencies.

Results – Hearing Threshold

	125 Hz	250 Hz	500 Hz	750 Hz	1000 Hz	2000 Hz	4000 Hz	8000 Hz
125 Hz	--	-1.8	-4.9	-5.0	-4.1	X	18.8	X
250 Hz		--	-3.2	-3.2	X	X	20.5	X
500 Hz			--	X	X	4.8	23.7	7.4
750 Hz				--	X	4.9	23.8	7.4
1000 Hz					--	4.0	22.9	6.5
2000 Hz						--	18.9	X
4000 Hz							--	-16.3
8000 Hz								--

Table 4: Pair-wise table indicating significant increase or decrease ($p < 0.05$) in SLT between frequencies

Results – Threshold Shifts

	S.L.T (OSHA)	S.L.T (Loggers)	STS	Percent Shift
1000 Hz	8.0	12.9	4.9	61.1%
2000 Hz	7.4	16.9	9.5	128.7%
4000 Hz	17.7	35.8	18.0	101.7%
Averages	**11.0**	**21.8**	**10.8**	**97.2%**

Table 5: Participants vs. OSHA hearing thresholds

Results – Hearing Protection

- Only significantly higher ($p < 0.05$) at 4000 Hz without HP.
- Significantly higher ($p < 0.05$) when combining all frequencies without HP.

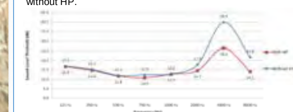


Figure 2: Mean hearing threshold with and without use of hearing protection

Results – Hearing Protection

Figure 3: Mean hearing threshold ***shift*** with and without use of hearing protection

Discussion

Discussion – Hearing Threshold

- The rate of hearing loss around the 4000 Hz region as a function of age does not present a linear relationship (Burns and Robinson, 1970).

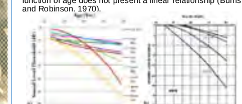


Figure 4: SLT of forest loggers **(a)** vs SLT of a normal population **(b)** (ASA, 1954)

Discussion – Hearing Protection

- Significant shift ($p < 0.05$) between participants with hearing protection and without was at 4000 Hz.
  - Gap between both groups was of 13.4 dB
- When averaging all frequencies together:
  - Mean hearing threshold was significantly higher for participants without hearing protection.
  - Average hearing threshold was 3.4 dB higher for these participants.

Acknowledgements

This project was sponsored by Louisiana State University Department of Industrial Engineering in cooperation with the LSU School of Renewable Natural Resources and the LSU AgCenter. Thanks to the following cooperators:
Slaughter Logging, LLC (Dennis Aucoin)
KS Logging (Malcolm Sibley)
Timberwolf Thinning Co. (Jason Doughty)
Louisiana Logging Council
Dr. Ashish Nimbarte..

Conclusions

- Significant hearing threshold shift found in loggers operating heavy equipment.
- Hearing threshold tends to increase more rapidly at 4000 Hz.
  - Gradually decreasing as frequencies decrease.
  - Reaching a low peak at 750 Hz and slowly increasing again at lower frequencies.
- The use of hearing protection helps minimize threshold shift, especially at higher frequencies such as 4000 Hz.

A Survey of Forest Engineering and Forest Operations Programs in North America

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In 1999 the *International Journal of Forest Engineering* published a special edition titled "Forest Engineering – Looking Ahead Ten Years." The lead article was "Graduate programs in forest engineering and forest operations: working towards extinction." McNeel, Stokes, and Brinker surveyed graduate programs in North America that had named graduate programs in forest engineering and forest operations (FE/FO) with a primary focus on PhD-level graduates. Concerns were raised over the low numbers of PhD graduates, aging FE/FO faculty, and declining employment opportunities for PhDs within traditional forest industry. These issues are still of significant concern; therefore, this survey has been repeated ten years later and expanded to include undergraduate programs and programs with options or emphasis areas in forest engineering, forest operations, and/or forest utilization. We compare our results with those reported in 1999 to establish a 10 year trend analysis while investigating the current and future viability of FE/FO programs throughout North America and implications to forest management and the wood products industry.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Some like it hot, some like it cold: Experience with biomass collection in western Oregon

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Abstract
The Coquille tribe of the central Oregon coast has been collecting slash since the fall of 2008 using roll-off containers, a truck with a hydraulic hook-lift, and a central concentration and grinding yard. While the initial concept was to use the roll-off bins as set-out containers at landings during logging operations, this has only occasionally worked operationally. Other configurations have included the hook-lift truck working within the rotation of log trucks and waiting at the landing while a bin is loaded as well as returning to pick up slash from road-side piles after logging operations have concluded. This paper will discuss the operational efficiencies (and inefficiencies), logistical consequences, unit and landing layout considerations, and cost tradeoffs of the several slash collection configurations experienced so far in this project.

Introduction
In the western US, a large volume of woody biomass is produced as slash created during forest treatments. With current technology and markets much of this volume is uneconomical to remove from the forest and is left on site or is piled and burned. However, with a push to develop renewable energy markets and decreasing opportunity for in-woods treatment of slash via open burning, many efforts are underway to operationalize the collection, transportation, and utilization of woody biomass. This paper will examine one of these efforts.

Transportation of woody biomass is primarily limited by the horizontal and vertical alignment of forest roads typically encountered in the western US (Rawlings et al. 2004). Historically woody biomass has been transported in ground form (hog fuel) in standard on-highway chip vans which are limited to high-standard roads in applications where it is economically feasible to grind material in the woods. This has lead to a proliferation of research into the use of two-staged transportation of slash utilizing a concentration yard. The goal of a two-stage transportation option is two-fold: first, to transport woody biomass in the form of slash from the landing to a concentration yard using a vehicle suited to lower-standard roads with poor horizontal and vertical alignment, and second to increase the efficiency of the grinding operation by concentrating a large volume of slash from multiple landings in one area accessible to both a grinder and high-capacity vehicles (eg. chip vans) for the transportation of hog fuel to market.

Study Site
The Coquille Indian Tribe (“CIT”), based in North Bend on the central Oregon coast, re-established federal recognition in 1989. In 1998 a small portion of CIT’s ancestral forestland was returned to the tribe’s management. One of CIT’s initiatives to increase the self-sustainability of its people resulted in a Woody Biomass Utilization Grant to purchase a hook-lift truck and bins and establish a concentration yard for the collection and sale of woody biomass. The initial idea was to use the roll-off bins as set-out containers on the landings of whole-tree commercial logging operations as in Rawlings et al. (2004). Collection began in October of

2008 and two grindings have taken place since in April 2009 and January 2010. The CIT collection yard is located immediately off a state highway. Table 1 summarizes the slash that has been collected as of the second grinding in January 2010.

Table 1: Summary of CIT slash collection October 2008-January 2010.

Sale Name	Grind	Hot or Cold Collection	Landowner	Logging System	Sale Volume (MBF)	Slash Volume (green tons)	Number of Bin Loads
Big Creek 4	2	Cold	Industrial	Cable	incomplete	405	37
Big Jones	Both	Both	Industrial	Cable	4680	1779	156
Chu#3	1	Cold	CIT	Cable	incomplete	677	53
Chu3	2	Both	CIT	Cable	incomplete	718	49
Elk Creek	2	Cold	CIT	Road Reconstruction	n/a	40	5
Euphoria Ridge	2	Cold	CIT	Cable	960	159	15
H-1	2	Cold	CIT	Cable	1260	691	59
Mead Creek	Both	Hot	CIT	Cable	incomplete	1793	182
Rasler Creek	2	Cold	CIT	Road Daylighting	n/a	307	37
Slide Creek	2	Cold	Industrial	Cable	2940	2149	230
Misc.	1					92	11
Total						**8807**	**834**

As is shown in the column "hot or cold collection" above in Table 1, the initial concept of using the roll-off bins as set-out containers for the collection of woody biomass as it is generated has not always worked. It was found that landings were generally too small for the bins to be used in this way. Instead, several different configurations have been used:

- Landings are modified so that there is space for two or more bins to be set out and full bins are collected at the end of the active logging shift.
- The hook-lift truck gets into the rotation of log trucks and, in turn, backs into the landing, unloads the roll-off bin for loading, the bin is loaded with slash and cull logs by the log loader, the bin is reloaded on the haul truck, and the slash is driven to the concentration yard or to a close by staging area where several bins can be placed.
- The logging contractor loads bins from road-side piles after logging operations have been completed but before moving out.
- An excavator is moved in after the completion of logging or road maintenance/reconstruction operations to load set-out bins from road-side slash piles. The hook-lift truck is continuously picking up full bins, delivering slash to the concentration yard, and returning to the woods with empty bins.

Slash collection has been employed on two main types of sales/projects: cable logging operations and road daylighting or reconstruction activities. In both cases, landing space is limited by the steep topography typical of the Coast Range. Only four of the logging operations have been completed.

Data Collection

As each load is delivered to the concentration yard, the hook-lift truck driver completes a trip ticket with the following information:

- Date
- Sale or project name
- Landing number
- Bin load time (minutes)
- Loaded trip time (minutes)

This date is entered along with sale attributes into a database maintained by CIT.

Results

Travel Time

Miles traveled on both rocked and paved roads influenced total travel time. This relationship is described by:

$$TT = 5.04 + 3.31R + 1.75P$$

(R^2 0.69, SE 7.43). Where TT is the one-way travel time in minutes, R is the miles of rocked road, and P represents the miles of paved road between the landing and the collection yard.

Slash Collection Costs

Slash collection costs were calculated assuming a fixed $65/hour for the hook-lift truck and driver and variable slash loading costs (Table 2). When possible, CIT attempts to minimize the variance of costs by paying contractors by the green ton, ranging from $2-2.67/ton, to load slash. This has worked when the logging contractor is still on site. When a separate excavator needs to be brought in to load slash after the completion of a sale, the excavator is paid at a rate of $88/hour. It was assumed that travel in the unloaded direction took a similar time to travel in the loaded direction and that unloading the slash at the collection yard took an average of 5 minutes. Bone dry tons were calculated assuming 35.3% moisture content, the average moisture content of ground material in January 2010.

Three sales, Elk Creek, Rasler Creek, and Euphoria Ridge, were all undertaken as clean-up operations on CIT lands to keep the hook-lift truck busy during down times. These were three of the most expensive sales to collect slash from and were not typical of the types of sales CIT is targeting for commercial slash collection. The most expensive sale to collect slash from was Big Jones. This was the first sale CIT completed after acquiring the hook-lift system and the high cost of slash collection reflects both CIT and the contractor learning the system.

Table 2: Summary of slash collection costs.

Sale/Project	Number of Bin Loads	Average Total Trip Time (minutes)	Average Trucking Cost per Bin	Average Loading Cost per Bin	$/green ton	$/bone dry ton
Big Creek 4	37	99	$107.16	$145.08	$23.77	$36.74
Big Jones	156	111	$120.53	$28.50	$13.48	$20.84
Chu#3	53	102	$110.48	$34.09	$11.43	$17.67
Chu3	49	113	$122.04	$36.61	$10.93	$16.89
Elk Creek	5	117	$126.75	$19.67	$18.92	$29.24
Euphoria Ridge	15	96	$103.64	$26.35	$13.10	$20.25
H-1	59	102	$111.00	$29.28	$12.25	$18.93
Mead Creek	182	79	$86.04	$19.70	$10.98	$16.96
Rasler Creek	37	125	$135.12	$20.66	$19.48	$30.11
Slide Creek	230	46	$ 49.95	$67.63	$12.79	$19.77
Misc.	11	124	$133.94	n/a	$17.07	$26.39
Overall	**834**	**85**	**$92.28**	**$42.61**	**$13.17**	**$20.36**

Grinding and Delivery Costs

Grinding was contracted for $12/green ton for both grinds. Hauling of ground "hog fuel" to the end user was completed utilizing a previously-empty backhaul, therefore was at a reduced rate of $4.66/green ton. With these costs included, total costs as shown in Table 3 were realized to get slash from the woods to the end-user.

Table 3: Total delivery costs per green ton (gt) and bone-dry ton (bdt) assuming 35.3% moisture content.

Sale/Project	Green tons	Loading ($/gt)	Hook-Lift Truck ($/gt)	Grinding ($/gt)	Chip Van Haul ($/gt)	Total Delivered Cost ($/gt)	Total Delivered Cost ($/bdt)
Big Creek 4	405	$13.27	$9.80	$12.00	$4.66	$39.73	$61.41
Big Jones	1779	$2.50	$10.57	$12.00	$4.66	$29.73	$45.95
Chu#3	677	$2.67	$8.65	$12.00	$4.66	$27.98	$43.25
Chu3	718	$2.50	$8.33	$12.00	$4.66	$27.49	$42.50
Elk Creek	40	$2.49	$16.04	$12.00	$4.66	$35.19	$54.40
Euphoria Ridge	159	$2.49	$9.79	$12.00	$4.66	$28.94	$44.73
H-1	691	$2.50	$9.48	$12.00	$4.66	$28.64	$44.26
Mead Creek	1793	$2.00	$8.73	$12.00	$4.66	$27.39	$42.34
Rasler Creek	307	$2.49	$16.29	$12.00	$4.66	$29.25	$54.77
Slide Creek	2149	$7.24	$5.35	$12.00	$4.66	$32.72	$45.20
n/a	92	$0.00	$16.06	$12.00	$4.66	$35.44	$50.57
Overall	**8807**	**$4.04**	**$8.74**	**$12.00**	**$4.66**	**$29.45**	**$45.51**

The total hog fuel purchase price came from three sources: the end user paid $31/bdt ton, a "BCAP" federal subsidy paid another $31/bdt, and a Oregon State tax credit produced revenue to CIT equal to $7/bdt for a total of $69/bdt. Comparing this rate to the last column in Table 3, all of the sales produced slash that could be sold at a net profit to CIT.

<u>Hot vs. Cold Loading Costs</u>

Not surprisingly, the two units where loading was paid by the hour to a contractor who moved in after logging operations were completed were four to seven times as expensive as paying the logging contractor to load slash either as an integrated part of the logging operation or before moving out as part of clean-up operations (Figure 1). It is important to note that total delivered biomass costs per green ton are not primarily influenced by slash loading arrangements. The Elk Creek and Rasler Creek sales had long haul times between the woods and the concentration yard. Hauls for these two units averaged 6 and 7 miles of gravel road, 10 and 11 miles of paved highway, for a total of 16 and 18 mile total hauls, respectivly. This is compared to an overall average of 3.3 miles of gravel road, 6.6 miles of paved highway, for a 9.9 mile total average one-way haul distance.

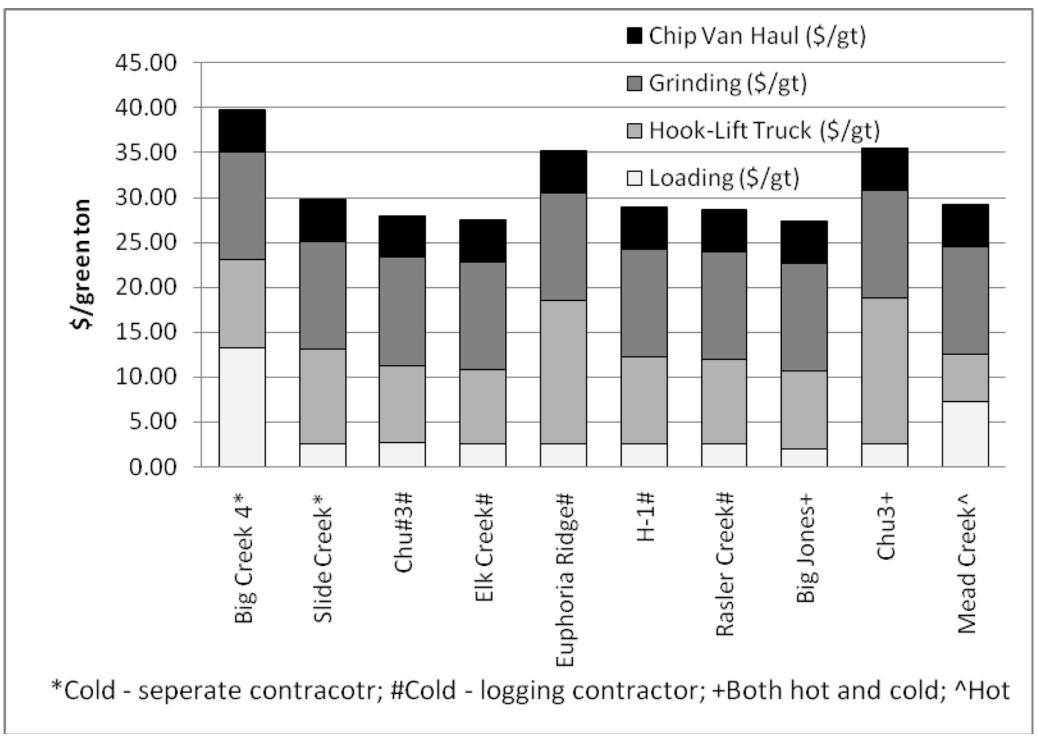

Figure 1: Comparison of total delivered cots per green ton by loading operation

<u>Slash Recovery</u>

Recovery rates for slash varied considerably across the four completed timber sales (Table 4). The age of the stands cut on industrial lands were 40-60 years old with the clear-cut stand on CIT land was nearly twice that age. With such a small sample size it is impossible to draw any conclusions regarding slash recovery rates.

Table 4: Slash recovery rates for completed sales.

Sale	Slash Collection	Landowner	Silvicultural Prescription	Sale Volume (MBF)	Slash Volume (green tons)	green ton/MBF
Big Jones	Both	Industrial	Clear-cut	4680	1779	0.38
Euphoria Ridge	Cold	CIT	Commercial Thin	960	159	0.17
H-1	Cold	CIT	Clear-cut	1260	691	0.55
Slide Creek	Cold	Industrial	Clear-cut	2940	2149	0.73

Discussion

Three sales, Chu#3, Chu3, and Mead Creek all required landing modification in order to allow for the use of roll-off bins for slash collection. In the Coast Range of Oregon with its steep topography, this can be an expensive and sometimes infeasible solution. Only one sale, Big Jones, which included some portion of hot collection of slash, did not require landing modification. This is an additional cost that needs to be considered in the total cost of slash collection.

Landowner and operator willingness to participate in slash collection had a big impact on the success of slash collection and also contributed to the extent of landing modification required. Those operators who believed the project would work made space on their landings for bins and arranged bin pick-up schedules with the hook-lift truck driver that allowed for efficient operations. Those operators who saw slash collection as an addition burden beyond their job description (despite a contract for slash loading services) did not make this extra effort and. Often in these cases slash was collected after the logging operation was completed in a given portion of the unit and it was not uncommon for slash to be located in piles too far from the road to be feasible to recover.

Conclusion

In an operation such as this with multiple slash collection scenarios, a large sample size not only of individual bin loads but of sale/project areas is needed to develop predictive relationships between stand and unit characteristics and delivered woody biomass costs. Clearly the 10 sales and 834 bin loads of slash represented here is inadequate to draw these conclusions. However, this dataset does allow CIT and others to see the impact of several variables (loading method and haul distance) on total costs and use this information to wisely choose future project sites.

Literature Cited

Rawlings, C., R. Rummer, C. Seeley, C. Thomas, D. Morrison, H. Han, L. Cheff, D. Atkins, D. Graham, and K. Windell. 2004. "A study of how to decrease the costs of collecting, processing, and transporting slash." Montana Community Development Corporation.

Trucking efficiency improvement through an analysis of in-woods turnaround times

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ABSTRACT

The transportation of raw forest products is an important component of any timber harvesting or wood supply system. In 2001 approximately 221 million tons of roundwood were transported by truck in the southern United States. The reliance on truck transportation for unmanufactured forest products stems from a variety of causes, including the improvement in road infrastructure, the reduction of rail lines, and changes in relative rail/road freight costs. However, costs associated with the harvest and transportation of forest products have increased by 14% from 1995 through 2003 while prices paid during the same period increased by only 8%. Trucking is often the most expensive phase of a timber harvesting operation, accounting for as much as 40-60% of total harvesting cost and over one-third of the delivered cost of wood in the cases of lower valued products such as pulpwood. Currently there is a lack of information concerning how tract and mill log truck turnaround times affect logging costs and trucking efficiency. This study evaluated truck turn times at the tract scale to identify important trucking productivity factors and efficiency improvement opportunities. Gross level studies of trucking operations in the Virginia Piedmont found that 1268 truck turns at the tract scale averaged 1.40 hours. Elemental time studies at harvesting locations found that log trucks were idle 32% of the time. Trucks spent the greatest amount of time loading while waiting was the second greatest contributor to turn times.

Introduction

The transportation of raw forest products is an important component of any timber harvesting or wood supply system. As of 1997, approximately 94% of the round wood delivered to processing facilities, across the United States, was transported by truck (BTS and USCB 1999). According to Smith et al. (2004), in 2001 approximately 221 million tons, of roundwood were transported by truck in the southern United States. The reliance on truck transportation for raw forest products stems from a variety of causes, including the improvement in hard surfaced road infrastructure, the reduction of rail lines, and changes in relative rail/road freight costs. Costs associated with the harvest and transportation of forest products increased by 14% from 1995 through 2003 while delivered wood prices paid during the same period increased by only 8% (Stuart et al. 2004).

Trucking is often the most expensive phase of a timber harvesting operation, accounting for as much as 40-60% of total harvesting cost (Shaffer and Stuart 1998) and over one-third of the delivered cost of wood for lower valued products such as pulpwood (Mendell and Haber 2006). Expenses associated with the transportation of harvested materials stems from high capital investments, high fuel and operating costs, and strict governmental regulations (Shaffer et al. 1986). As a result, modest transportation efficiency gains could produce meaningful cost savings.

This study was conducted with the assistance of one logging business that operates four separate harvesting crews and approximately 34 log trucks, of which 14 truck drivers were company employees and 20 truck drivers were independent contractors. Each harvesting crew operated primarily in the Piedmont of Virginia while products were delivered as far away as Pennsylvania. Each crew had unique equipment configurations and operated on different forest stands under differing harvest prescriptions. Forest roads observed during the course of the study included both class permanent and temporary forest roads that were not part of county, state, or federal road systems.

Methods

Crew one consisted of one TigerCat 724E feller-buncher paired with one TigerCat 635B rubber-tired grapple skidder as well as one Timbco 820E rubber-tired grapple skidder. This crew also utilized one Barko 495M knuckleboom loader with a CTR delimber and one Barko 595 knuckleboom loader. Crew one also employed one deck hand who was responsible for delimbing loaded trucks using a pole saw as well as moving set out trailers. This crew also utilized platform scales and one bunk saw. Crew one was working on a 100 acre loblolly pine plantation receiving the first thinning. Crew one utilized a class three road with a total length of 1,330 feet and an average width of 22 feet. During the course of the study the weather remained clear and the road stayed dry.

Crew two consisted of one TigerCat 720D feller-buncher paired with one TigerCat 630C rubber-tired grapple skidder. This crew utilized two Barko 495M knuckleboom loaders, one of which was equipped with a CTR delimber. Crew two also employed one deck hand who was responsible for delimbing loaded trucks using a pole saw as well as moving set out trailers. This crew was also equipped with platform scales and one bunk saw. Crew two was working on a 60 acre loblolly pine plantation receiving its first thinning. Crew two utilized a class three road with a total length of 3,168 feet with an average width of 14 feet. During the course of the study the weather was clear with dry roads with the exception of morning one Friday which received less than 1 inch of rain. During this half day the road became impassable for loaded log trucks and work was not resumed until the following Monday.

Crew three consisted of one TigerCat 724E feller-buncher paired with one TigerCat 635B rubber-tired grapple skidder. This crew utilized one Barko 495M knuckleboom loader with a CTR delimber and one Barko 595 knuckleboom loader which was paired with a bunk saw. Crew three also employed one deck hand who was responsible for delimbing loaded trucks and moving set out trailers. Crew three was working on a 600 acre loblolly pine plantation clear cut harvest. Crew three utilized a class three road with a total length of 5,808 feet with an average width of 16.5 feet. During the course of the study the weather remained clear and the road remained dry.

Crew four consisted of one TigerCat 720D feller-buncher paired with one TigerCat 630C rubber-tired grapple skidder. This crew also utilized one Barko 495M knuckleboom loader paired with a CTR delimber. Crew four was working on a 400 acre loblolly pine plantation receiving its first thinning. Crew four utilized a class four road with a total length of 11,088 feet and an average width of 15 feet. During the course of the study the weather remained clear and the road remained dry.

The first phase of data collection consisted of a gross time study which began on July 13th and continued until November 17th 2009. A gross time study deals with gross production, total elapsed time, and typically involves those responsible for production to record these values (Miyata et al. 1992). During this phase, 34 truck drivers recorded data in the gross time study. Seventeen truck drivers were randomly assigned to record tract turn times starting when the truck exited a state or county maintained road to enter a harvesting location and ending when the truck reentered a state or county maintained road. During this phase, truck drivers recorded date, weather, product, road length, time in/out, crew number, and destination. A total of 1268 tract turn times were recorded.

The second phase of data collection consisted of an elemental time study which was conducted at each of the four harvesting locations as well as at each of the three mill facilities. Elemental time studies utilize stopwatches in observing, measuring, and recording well-defined phases of operations for an entire day or over many days or weeks (Miyata et al. 1992). Fifty in-woods truck turns were observed at each of the four harvesting crews for a total of 200 turns. A turn was defined as beginning when the log truck exited a state or county maintained road entering a harvesting location and ending when the truck returned to the state or county maintained road. Crew specific information, including the number of employees and specific equipment mixes, was recorded for each harvesting crew. Stand specific information was also recorded for each location including tract size and harvest prescription.

A combination of general information and various time elements were gathered for each truck turn. General information consisted of date, crew number, road length, road width, road condition, weather, time of day, load type, product, and loading method. Time elements covered all possible tasks that a log truck can be involved in during one turn. Time elements are shown in detail in Table 1.

Statistical analysis consisted of developing stepwise multiple linear regression models for predicting truck turn times at both the tract and mill levels. Models were evaluated using the multiple R-squared, the standard deviation of the residuals ($S_{y.x}$), and the F-statistic. Comparisons between company and contract trucks were completed using a One-Way Analysis of Variance (ANOVA). Comparisons between turn times during the morning and afternoons, were completed using and ANOVA.

Table 1: Description of tract time elements.

Travel Loaded (TL)- Time spent traveling loaded
Travel Empty (TE)- Time spent traveling empty
Delay Mechanical (DM)- Truck break downs, etc.
Delay Non-mechanical (DNM)-Talking, cell phones, etc.
Waiting (WT)- Time spent idle due to interactions or bottlenecks
Positioning (POS)- Time spent backing under a loader or trailer
Loading (LD)- Time spent under a loader
Preparing the load (PTL)- Time spent trimming the load, attaching flagging, and binding the load.
Drop off trailer (DOT)- Time spent disconnecting glad hands and dropping landing gear
Pick up trailer (PUT)- Time spent connecting glad hands and raising landing gear

Results and Discussion

Results of the gross level time study are shown in Table 2**.** Contract trucks make up approximately 60% of the studied truck fleet yet accounted for less than 49% of the 1,844 recorded loads. The majority of the loads delivered by contract trucks were delivered to a receiving mill in Pennsylvania. However, company owned trucks never transported raw forest products to the Pennsylvania mill. This resulted in contract trucks often only receiving one load a day as opposed to company trucks which received multiple loads. Due to these differences a ANOVA with α=0.05 was conducted to determine if there were significant differences between company and contract truck turn times at the tract level. The test indicated that there was no significant difference between company and contract truck turn times (p=0.70).

Table 2: Gross level descriptive statistics.

	Count	Mean (Hours)	Min (Hours)	Max (Hours)	Range (Hours)	SD	SE
Company	606	1.32	0.11	6.50	6.39	0.91	0.03
Contract	662	1.47	0.17	6.50	6.33	1.25	0.04
Combined	1268	1.40	0.11	6.50	6.39	1.11	0.03

Tract turn times, with company and contract truck turn times combined, ranged from 0.11 to 6.50 hours with an average turn time of 1.40 hours and a median of 1.0 hours. The minimum turn times reflect the shortest turn times recorded for set out trailers while the longest turn times are associated with hot loading. Each crew worked from 7:00 am until 5:00 pm and took a 30 minute lunch break at 12:00 pm. Using the recorded starting time of each turn it was determined that of the 1,268 recorded tract turn times 60% occurred before 12:00 pm while the remaining turns occurred after the crew's lunch break. The average morning turn time was 1.15 hours while the average afternoon turn time increased to 1.55 hours. An ANOVA with α=0.05 determined that there was a significant difference between morning and afternoon turn times (p=0.28).

Elemental descriptive statistics (Table 3**)** were summarized for the total turn time for each crew. The longest turn times were recorded for crew four. This crew also had the longest haul road distance with a total distance of 2.1 miles from the state maintained road to the logging deck. Each of the four crews used a combination of setout trailers and hot loading during the course of the study. Hot loading is used on logging operations in which the stems are not decked and stored for extended periods of time but loaded onto a truck as soon as a truck is available. Setout trailers are trailers that are loaded and prepared for transport in the absence of available trucks for hot loading. The shortest turn times recorded during the elemental time study were those of the setout trailers while the longest recorded turn times are associated with hot loading.

Table 3: Elemental tract descriptive statistics for all crews.

	Count	Mean (hours)	Min (hours)	Max (hours)	Range (hours)	SD	SE
Crew 1							
Hot	30	1.38	0.41	3.78	3.37	0.87	0.12
Setout	20	0.44	0.19	1.69	1.49	0.34	0.08
Crew 2							
Hot	27	1.81	0.58	3.4	2.82	0.81	0.16
Setout	23	0.64	0.18	1.74	1.56	0.53	0.11
Crew 3							
Hot	41	1.51	0.65	3.7	3.05	0.7	0.11
Setout	9	0.56	0.39	0.7	0.31	0.12	0.05
Crew 4							
Hot	37	2.08	1.26	3.95	2.69	0.56	0.09
Setout	13	0.76	0.21	1.52	1.31	0.38	0.12
Combined							
Hot	135	1.69	0.41	3.95	3.54	0.77	0.07
Setout	65	0.59	0.18	1.74	1.56	0.43	0.05
All	200	1.34	0.18	3.95	3.77	0.85	0.06

In all harvesting systems, the use of setout trailers resulted in shorter turn times versus hot loading. As shown in Table 3 the average setout turn time was 0.59 hours while the average hot loading turn time was 1.69 hours. The longest setout trailer turn times reflect times in which trucks arrived to the harvesting location when no setout trailers were available but were being loaded. In this situation, trucks often waited for the set out trailer to be completely loaded and then took that load. This situation contributed to the longest setout trailer turn times. Given the difference in average turn times between setout trailers and hot loading, tract turn times for harvesting contractors could potentially be reduced if setout trailers were more commonly incorporated.

Of the 136 tract turn times which were identified as hot loading 86, or 63% occurred in the morning while the remaining 37% occurred in the afternoon. The average turn time recorded in the morning was 1.65 hours while the average afternoon turn time was 1.67 hours. Using an ANOVA test with $\alpha=0.05$ it was determined that there was no significant difference between hot loading which occurred in the morning or afternoon. Of the 64 tract turn times which were identified as setout trailers 70% occurred in the morning while the remaining 30% occurred in the afternoon. The median morning turn time was 0.38 hours while the afternoon turn time had increased to approximately 0.51 hours. Using an ANOVA with $\alpha=0.05$ it was determined that there was no significant difference between morning and afternoon setout turn times ($p=0.17$).

A comparison was also made between tract turn times for both the gross and elemental time study. Using an ANOVA with $\alpha=0.05$ it was determined that there was no significant difference between gross and elemental tract turn times ($p=0.83$).

Two multiple linear regression models were developed for predicting tract turn times. These models were selected due to the differences in overall turn time for hot loading and setout trailers and can be used to predict turn times for hot loading or using setout trailers. Descriptive statistics (Table 4) were summarized for the different time elements used in each of the following models.

Table 4: Descriptive statistics for hot loading and setout trailer model inputs.

	Count	Mean	Min	Max	Range	SD	SE
Hot Loading							
LD	135	0.59	0.12	2.28	2.16	0.33	0.03
TE	135	0.15	0.14	0.44	0.3	0.11	0.009
WT	135	0.44	0	1.96	1.96	0.49	0.04
Setout Trailers							
DNM	65	0.09	0	1.33	1.33	0.2	0.03
TL	65	0.07	0.01	0.33	0.32	0.08	0.01
WT	65	0.11	0	1.43	1.43	0.32	0.04

For hot loading at the tract scale, 135 loads total, the independent variables waiting (WT), loading (LD), and travel empty (TE) were significant. Tract turn time (hours) for hot loading:

Model 1. ($y = 0.27 + 1.12 \times LD + 1.99 \times TE + 1.05 \times WT$)
$R^2=0.90$, F-ratio=418.66, $S_{y.x}=0.05$, p-value<0.001

In model one the variables LD, TE, and WT were once again used. As before these variables represent time spent loading, traveling empty, and waiting respectively. All time elements are in hours as is the total estimated turn time. Turn time estimated using model one appear in Figure 1. To create these estimates the average loading time of 0.59 hours and the average travel empty time of 0.15 hours were used. Waiting times were increased from 0 to 2 hours which represented the range of observed waiting times for all loads. Using model two errors for the estimate ranged from -1.86 to 1.16 hours with an average error for the estimate of 0.01 hours.

For setout trailers at the tract scale, 65 loads total, the independent variables waiting (WT), delay non-mechanical (DNM), and travel loaded (TL) were significant. Tract turn time (hours) for setout trailers:

Model 2. ($y = 0.21 + 1.06 \times DNM + 2.33 \times TL + 1.05 \times WT$)
$R^2=0.95$, F-ratio=396.80, $S_{y.x}=0.09$, p-value<0.001

In model two DNM, TL, and WT represent time spent in non-mechanical delays, traveling loaded, and waiting respectively. All time elements are in hours as is the total estimated turn time. Turn time estimated using model two appear in Figure 2. To create these estimates the average non-mechanical delay time of 0.10 hours and the average travel loaded time of 0.07 hours were used. Waiting times were increased from 0 to 1.43 hours which represented the range of observed waiting times for all loads. Using model three, errors for the estimate ranged from -0.23 to -0.27 hours with an average error for the estimate of -0.006 hours.

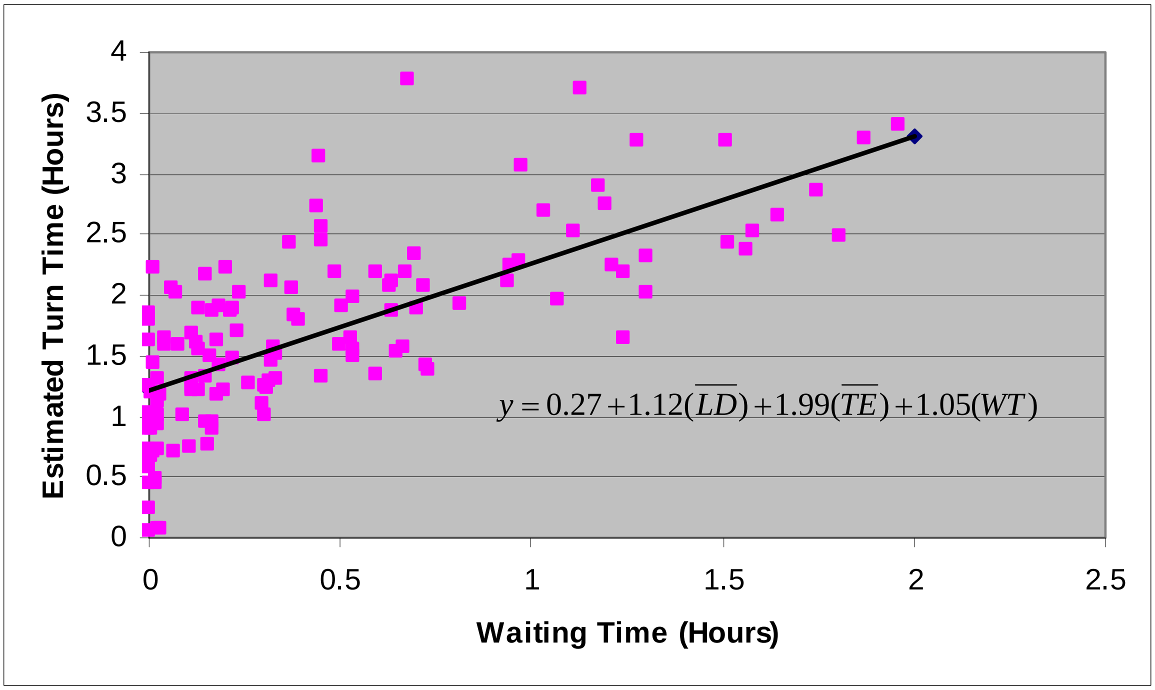

Figure 1: Estimated turn times for hot loading with loading and travel empty held at the average observed value.

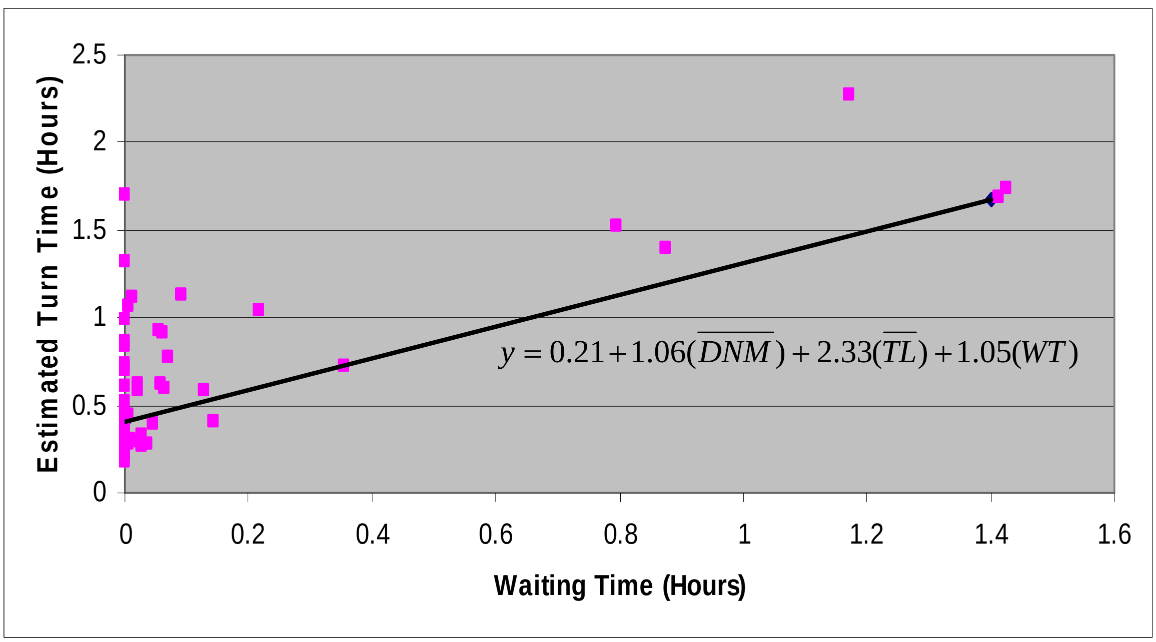

Figure 2: Estimated turn times for setout trailers with delay non-mechanical and travel loaded held at the average observed value.

Conclusions

Loading and waiting times were the major contributors to tract turn times with a total of 29 and 26% respectively. As such, reductions in time spent waiting and loading could significantly reduce tract turn times. Over the course of the study an average of 9 trucks were hot loaded per day. If the average turn time were reduced by 25% a total of 81 minutes would be saved each day. This would allow enough time to load 3 more trucks or setout trailers while a 50% reduction would save 162 minutes allowing enough time to load 9 more trucks or setout trailers. A 25 or 50% reduction in waiting times would save 63 and 126 minutes respectively. This saved time would allow 2 to 3 additional loads each day.

The majority of time spent waiting was due to two bottlenecks, the first being a lack of wood ready to be loaded onto a waiting truck and the second being one truck waiting to be loaded due to another truck currently being loaded. As such, it would not be unreasonable for reductions in loading time to cause reductions in waiting time. A 25% reduction in both loading and waiting times would save 144 minutes each day making it possible to load an additional 5 trucks or setout trailers. A 50% reduction in both loading and waiting times would save 279 minutes each day which would be enough time to load 15 additional trucks or setout trailers.

During the course of the study the greatest impediment to truck turn time was keeping the loader supplied with enough wood to load trucks. This appeared to be caused by unbalanced logging crews. Harvest contractors should try to ensure that equipment mixes are suited for the harvest prescription and site on which they will be working. Crew one, which operates primarily on clear cuts, was operating on a young pine thinning with relatively small pulpwood. Had this crew been operating on a clear cut the crew's production would have likely been much different. Both crew two and crew three identified skidding as their limiting factor. In both cases the feller-buncher had more than enough wood on the ground to keep the skidder working however long skidding distances were not allowing the skidder to work as efficiently as possible.

While the overall variability of harvesting will keep some aspect of harvest production and trucking efficiency out of contractor control, any possible efficiency improvement opportunities should be fully explored and, when feasible, implemented. Harvest contractors should also take steps to reduce the amount of time that is wasted, not only during each truck turn, but throughout the harvesting system. During the course of the study the average non-mechanical delay time was approximately 10 minutes. Non-mechanical delays typically occurred when truck drivers were using cellular phones, talking, etc.

When questioned about moving towards a cold logging system, where crews move onto a tract and load trailers before trucks arrive the harvest contractor indicated that this approach had been tried before. Previously a crew would work 2-3 days loading trailers before trucks started to haul from that particular crew. As additional crews and mill destinations were added it became difficult to coordinate log trucks as well has keep enough trailers available to be loaded. There is no "best" solution for trucking raw forest products in terms of hot loading versus the use of setout trailers. Harvest contractors should balance the costs and benefits of each option and use the most appropriate approach as each harvesting site dictates.

Literature Cited

Brinker, R.W., J. Kinard, B. Rummer, and B. Lanford. 2002. Machine rates for selected forest harvesting machines. Alabama Agricultural Experiment Station. Circular 296. 32 p.

Bureau of Transportation Statistics (BTS) and U.S. Census Bureau (USCB). 1999. *1997 United States Commodity Flow Survey*. U.S. Census Bureau. EC97TCF-US. 169 p.

Gallagher T., T. McDonald, M. Smidt, and R. Tufts. 2005. Let's talk trucking: Weights and loading methods. Forest Resources Association Tech. Pap. 05-P-2.

Laestadius, Lars. 1990. A comparative analysis of wood-supply systems from a cross-cultural perspective. PhD. dissertation, Virginia Polytechnic Institute and State University, Blacksburg, Virginia. 149 p.

Mendell, B.C. and J.A. Haber. 2006. Evaluating the potential for shared log truck resources in middle Georgia. South. J. Appl. For. 30(2): 86-91.

Miyata, E.S., H.M. Steinhilb, and S.A. Winsauer. 1992. Using work sampling to analyze logging operations. United States Department of Agriculture. Research paper Nc-213. 9 p.

Shaffer, R.M. and W.B. Stuart. 1998. A checklist for efficient log trucking. Virginia Cooperative Extension. Virginia Tech. 17.Available online at http://www.ext.vt.edu/pubs/forestry/420-094/420-094.html; last accessed Nov. 7, 2008.

Smith, W.B., P.D. Miles, J.S. Vissage, and S.A. Pugh. 2004. Forest resources of the United States, 2002. USDA For. Serv. Gen. Tech. Rep. NC-241. 137 p.

Stuart, W., L. Grace, and C. Altizer. 2004. Preliminary 2003 logging cost indices. Wood Supply Research Institute and the Forest and Wildlife Research Center- Mississippi State University, FWRC FO 415. 18 P.

Timber Mart-South, Inc. 2009. Logging Rates. The Journal of Southern Timber Prices. 34 (1): 14-15.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Forest Roads and Flooding

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Abstract

Forest harvesting and road building can potentially affect stream discharge. A distributed hydrology-soil-vegetation model (DHSVM) was used to investigate the relationship between forest road density and stream response. DHSVM is a spatially explicit model that has the ability to incorporate road networks into its hydrologic calculations. This is of critical importance because it has long been recognized that forest roads can have large impacts on water yields and water quality. The primary objectives of this project were to calibrate DHSVM to the Blue Ridge Mountains and to determine whether or not typical forest road densities affect stream discharge. Calibration of the model was done using historical data collected from the Coweeta Long Term Ecological Research Station in the Blue Ridge Mountains of North Carolina. Road networks were created for densities of 0.8, 1.6, 4.8, 9.7, and 19.3 mi mi^{-2}. The current road density of the study watershed is 6.9 mi mi^{-2}. Changes in stream discharge were seen in road densities greater than 6.9 mi mi^{-2}. Highly significant differences in stream discharge were seen at densities greater than 9.7 mi mi^{-2}. In order to decrease the impact of roads on streamflow, forest managers should minimize road densities while using appropriate water control best management practices.

Introduction

Flooding effects are extremely important in the hurricane-prone region of the Southeastern United States. In the heavy hurricane years of 2004 and 2005, damages from such hurricanes topped $150 billion (Pielke et al., 2008). The heightened public awareness of flood events has generated interest in the management of forested watersheds, which have been suggested to buffer the impacts of flooding (Cornish and Vertessy, 2001).

Impacts of forest harvesting on the stream hydrograph are important yet transient, since re-vegetation of the landscape generally occurs within five years of logging (Hewlett and Helvey, 1970; Hornbeck et al., 1970; Swank et al., 2001). Forest roads, however, can potentially leave permanent impacts on the ecosystem. One impact of concern is how forest roads affect watershed hydrology. A road can affect the hydrology of a forested ecosystem through three different processes:

1) *Interception of Subsurface Flow*: the water table rises above the road cut and subsurface flow seeps into the road network and drainage system and is channeled down the road;
2) *Infiltration Excess Runoff*: the compacted road surface decreases the infiltration capacity of the soil and the excess water becomes runoff;
3) *Overland Flow*: the road and drainage system intercepts overland flow and re-routes it from the hillslope through the road network.

These processes can alter the stream hydrograph, both in quantity and in timing and can lead to potential flooding for downstream communities. It can be difficult to study the effects of forest roads because road construction and installation are often concurrent with forest harvesting efforts. However, the development of complex and sophisticated hydrologic models has allowed researchers to simulate the watershed environment and effectively study the potential impacts of road networks. One such model, the Distributed Hydrology-Soil-Vegetation Model (DHSVM) has been used in numerous attempts to study various aspects of logging and road building (Bowling and Lettenmaier, 1997; Bowling et al., 2000; Cuo et al., 2006; Doten et al., 2006; La Marche and Lettenmaier, 2001; VanShaar et al., 2002).

This study was motivated by litigation surrounding forest management activities, such as harvesting and road construction, and how they might affect flood events. Since several current hydrologic models have the power to handle the complexity of forested ecosystems, a modeling approach will be used. Specifically, DHSVM will be used to predict the impacts of forest road density on stream discharge. This model was chosen because it has enhanced capabilities for modeling different road designs and densities. The specific objectives of this research are to:

1) Determine whether or not DHSVM can be calibrated for use in the Southern Appalachian Mountains; and
2) Assess the impacts of forest road density on stream discharge.

Methods

Site Description

This study was conducted using historical data from the Coweeta Long Term Ecological Research Station (LTER) in the Blue Ridge Mountains of Western North Carolina (35°03′N, 83°25′W) (Douglass and Hoover, 1988). The site contains over 50 watersheds with a combined area of 8.4 mi^2. This study focused on the 2.9 mi^2 Shope Fork catchment (Figure 1). Elevations at Coweeta range from 2215 ft to 5215 ft with sideslopes ranging from 50 to 60% (Swank and Crossley, 1988). Precipitation is primarily in the form of rainfall (90 to 98%) and is most abundant during the winter months. Mean annual precipitation is approximately 71 in. Average temperatures range from winter lows of 25°F to summer highs of 73°F (Swift et al., 1988). Major soil orders include Inceptisols and Ultisols and textures are predominately sandy loams (Swank and Crossley, 1988). In 2009, the Shope Fork catchment had a road density of 6.9 mi mi^{-2}. Roads included a range of road standards from graveled all weather access roads (Class I) to closed grassed harvest roads (Class III).

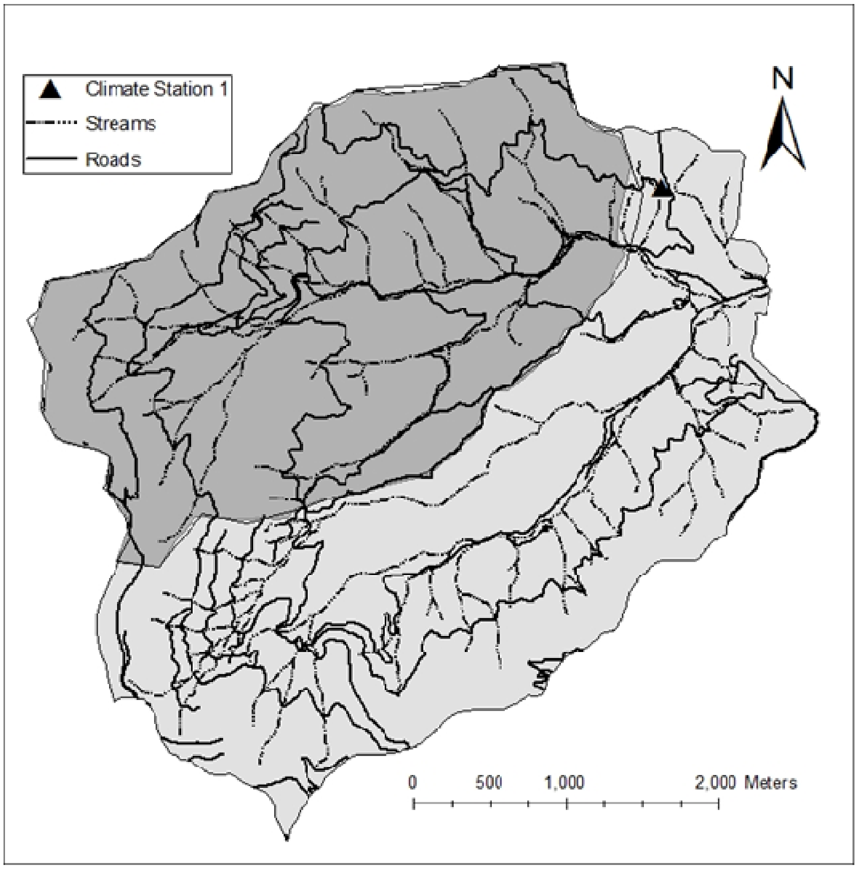

Figure 1 The 2.9 mi^2 study site (dark gray) is located in the northern portion of the Coweeta basin (light gray).

Model Input

The Distributed Hydrology-Soil-Vegetation Model (DHSVM) is a physically based hydrologic model and operates at the scale of a grid cell. At a specified time step, the model will calculate the energy and water budgets for the entire watershed. Detailed information can be found in Wigmosta et al. 1994 and 2002 and Storck et al. 1998. Because DHSVM is based on physical processes, inputs are numerous and comprehensive. Spatial data are required for elevation, soil (type and depth), vegetation, and watershed boundaries. For this study, a 30 m DEM for the Prentiss Quadrangle was downloaded from the GeoCommunity forum (GeoCommunity, 2007). Soil inputs were obtained from the Natural Resource Conservation Service (NRCS) Soil Survey Geographic (SSURGO) database (Soil Survey Staff, 2008). Soil depth maps were manually created in ArcMap (Hillier, 2007) and were based upon maximum soil depths found in the Macon County, North Carolina Soil Survey (Thomas et al., 1996). Vegetative cover types were also manually created in ArcMap, and were based upon a combination of elevation, moisture regime, and aspect (Day et al., 1988). Two types of spatial networks are required for DHSVM; streams, which are mandatory, and roads, which are optional. Stream and road shapefiles were downloaded from the LTER GIS dataset (Coweeta LTER, 2008).

Detailed soil, vegetation, and meteorological parameters are required by the model. While most variables can be physically measured, this study attempted to use data based on available historical records and literature values. Most meteorological data were obtained from the Coweeta LTER.

DHSVM Calibration

DHSVM was calibrated to the Shope Fork watershed through comparison with historical data from Coweeta Weir 8. Calibration was from October 1, 2003 through September 30, 2004 and model validation was from October 1, 2004 through September 30, 2007. The model was initially run from January 1, 2003 through September 30, 2003 to ensure adaptability to parameter settings. Model state variables from this warm-up period were used for the calibration settings and likewise the calibration variables were used to initiate validation runs. Precipitation for the calibration period totaled 70 in. and was considered a normal precipitation year. The three years following the calibration were used as a validation of the model. The calibration was followed by one exceedingly wet year and two comparatively dry years (86, 57, and 58 in., respectively). Changes to input parameters were made in order to minimize differences between observed and predicted stream discharge. Alterations were made primarily to the lateral saturated hydraulic conductivity and exponential decrease input parameters, as studies have shown DHSVM to be sensitive to these variables (Bowling and Lettenmaier, 1997; Wigmosta and Lettenmaier, 1999). In agreement with Cuo et al. (2006), it was found that increasing the accuracy of peak flow resulted in a decrease of baseflow precision and vice versa.

Assessment of the calibration and validation was determined through analysis of the timing of the model hydrograph, volume of the hydrograph, and overall model accuracy. The correlation coefficient (R) was used to analyze the accuracy of the predicted hydrograph and a value of 1.0 was desired. The average volume error between the predicted and observed discharge ($\Delta V/V$) was used to look at DHSVM's ability to accurately simulate peak flows. Overall model accuracy was determined using the correlation coefficient (R^2). Similar statistical methods have been used in Beckers and Alila (2004), Cuo et al. (2006), Thyer et al. (2004), and Wigmosta and Burges (1997).

Road Density Experiment

Experimental treatment densities were chosen to reflect typical forest road densities, which usually range from 1.6 to 9.7 mi mi^{-2} (Bowling and Lettenmaier, 1997; Hawbaker et al., 2005; National Forests in North Carolina: Fiscal Year 2007). In 2009, the road density of Shope Fork was 6.9 mi mi^{-2}. Modeled treatment densities (Table 1) were designed to emulate actual forest road densities. In the United States, it is estimated that all state maintained roads have an average density of 1.9 mi mi^{-2} (Forman, 2000). Treatment replications were done in the form of three different layouts at each density. Isolating density was difficult, however, since many uncontrolled outside factors can impact stream discharge. Such confounding factors include the spatial location of the road with relation to streams, the gradient or slope of the road, the surfacing material of the road, road design features (such as insloped, outsloped, and crowned roads), the water control features of the road, number of stream crossings, and length of the road.

An approach was used that amalgamated road position, slope, and class into one impact factor that describes the overall relative effect of the road on the watershed (Bernard, 2006) (Figure 2). This impact factor was divided by the treatment road length to get a weighted impact factor (RIF). The average RIF was kept as consistent as possible throughout each treatment. Road surfacing and design features were included in the class of the road and were also controlled.

Table 1 Treatment used in calibration of DHSVM for Shope Fork catchment.

Treatment	Road Density (mi mi^{-2})	Road Length (mi)	% Area in Roads	Replications
1	0.8	2.4	0.3	3
2	1.6	4.8	0.5	3
3	4.8	14.6	1.2	3
Control (4)*	6.9	20.9	1.8	3
5	9.7	29.2	2.6	3
6	19.3	58.4	5.6	3

* Road density of the Coweeta LTER as of 2009.

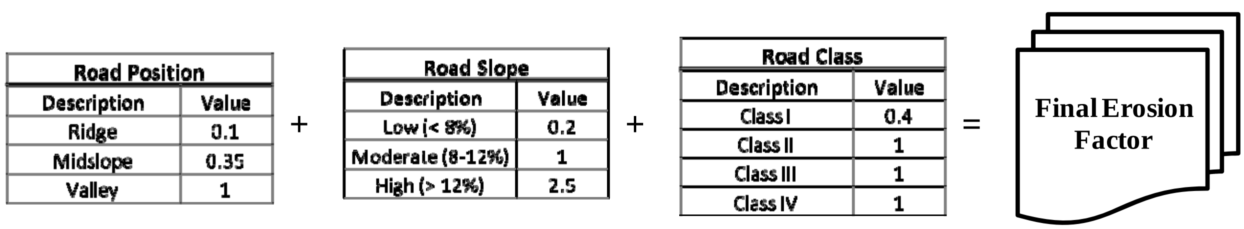

Figure 2 The Final Erosion Factor is based on weighted values of the impact factors, which include road position, slope, and class (Bernard, 2006).

Analysis of road density effects compared streamflow between treatments over the entire calibration and validation period. One sample (Layout 1, Density 5) suffered unidentifiable error and was discarded from the study. Using Statistical Analysis Software (SAS/STAT Software, Version 9.2), the data were determined to be normal via proc univariate. A proc mixed statement with compound symmetry was used to model the covariance structure of the data and a Tukey-Kramer analysis for parsing out individual road density effects.

Results

Calibration and Validation of Shope Fork

Statistics suggest that DHSVM was calibrated for Shope Fork with reasonable accuracy. While the model was successful in predicting the general trends of the hydrograph, both over and under predictions of streamflow occurred during peak discharge. Discrepancies between both the volume predictions and timing of peak flows were evident when looking at the statistical parameters (Table 2). The R^2 was lower than desired as DHSVM predicted less than 50% of the initial variance of the original data. For DHSVM, known R^2 range from 0.61 to 0.96 (Beckers and Alila, 2004; Cuo et al., 2006; Leung et al., 1996; Thyer et al., 2004; Wigmosta and Burges, 1997).

The validation period was consistent with the calibration in that DHSVM predicted the general trends of the hydrograph but had trouble predicting peak flows. Although water year 2005 is representative of a higher than normal degree of tropical storm and remnant activity from the Atlantic region, the average volume error for the year was the lowest of the entire testing period. Over the entire validation period, volume error averaged to be null. Timing for the validation period increased relative to the calibration (R = 0.85). The decrease in volume error and increase in timing accuracy created improved model efficiency during the validation period of 0.73.

Table 2 Calibration and validation statistics for Shope Fork catchment.

WYR	Total Precip. (in.)	$\Delta V/V$	R	R^2
2004	70	0.10	0.69	0.48
2005	86	0.06	0.79	0.63
2006	57	-0.13	0.88	0.78
2007	58	0.07	0.89	0.80
Calibration	70	0.10	0.69	0.48
Validation	67	0.00	0.85	0.73

Road Density Experiment

Results suggest that increases in road density can create increases in mean annual streamflow

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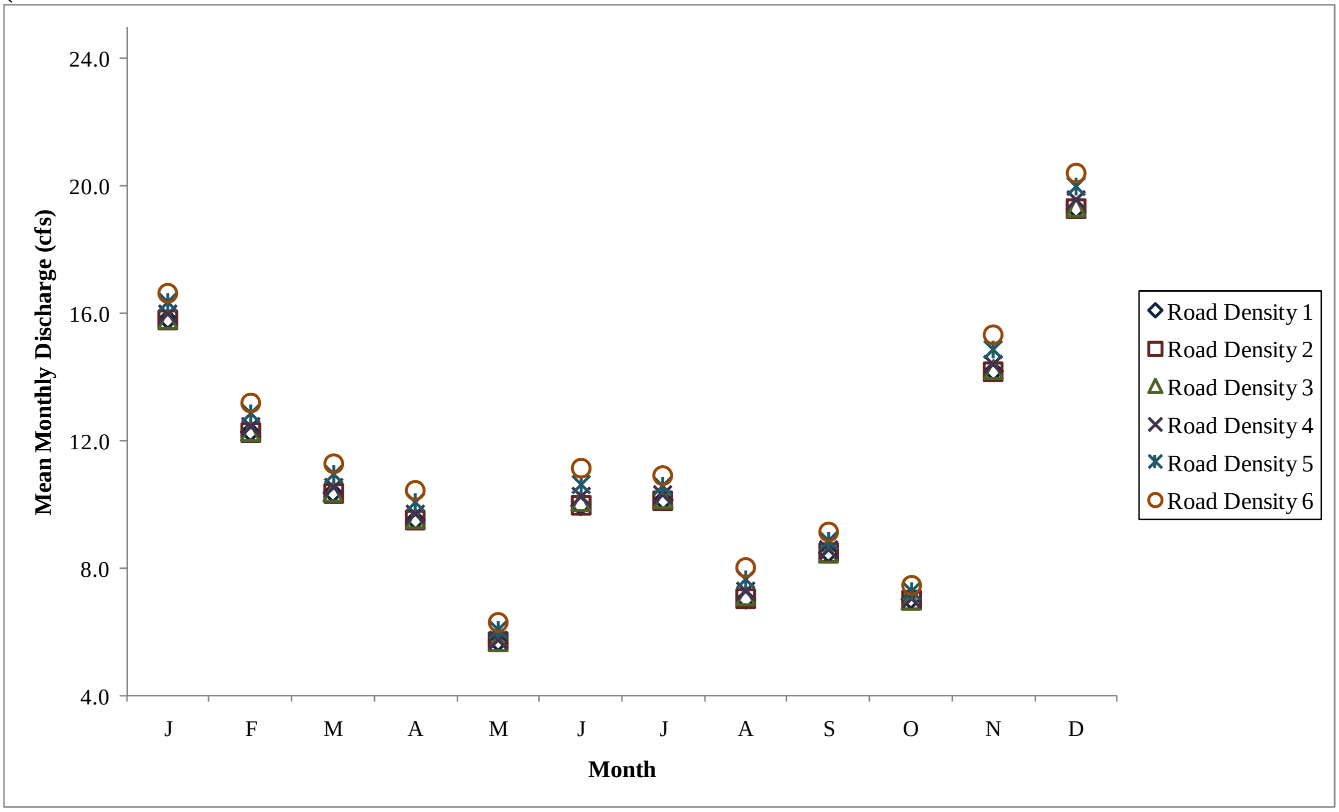

Figure **3**). In most months, stream discharge increased with an increase in road density, although this relationship was not linear. Exceptions occurred in January and October, where streamflows resulting from 1.6 km km^{-2} road densities were slightly higher than those from 0.8 mi mi^{-2} simulations. The magnitude of mean streamflow was not dependent upon mean monthly precipitation, suggesting factors other than precipitation volume were important in controlling streamflow. The variation in response between the treatments did not change with relation to the volume of discharge, nor with the month. Road effects on stream discharge were found to be significant and were confirmed by Analysis-of-Variance (ANOVA) using Type III sum of squares with a significance level of <0.0001.

DHSVM results indicate a significant change in streamflow at road densities ≥ 6.9 mi mi^{-2} (Table 3). Highly significant differences occurred at the 9.7 mi mi^{-2} and 19.3 mi mi^{-2} densities. These results suggest that streams have an altered response when forest road densities reach 6.9 mi mi^{-2} and that it is desirable to keep maximum road densities between 4.8 and 6.9 mi mi^{-2}. Using DHSVM to model the effects of roads on streamflow, Bowling and Lettenmaier (1997) found that road densities of 12.9 and 16.1 mi mi^{-2} increased streamflow of ten year floods by 8 and 10%, respectively.

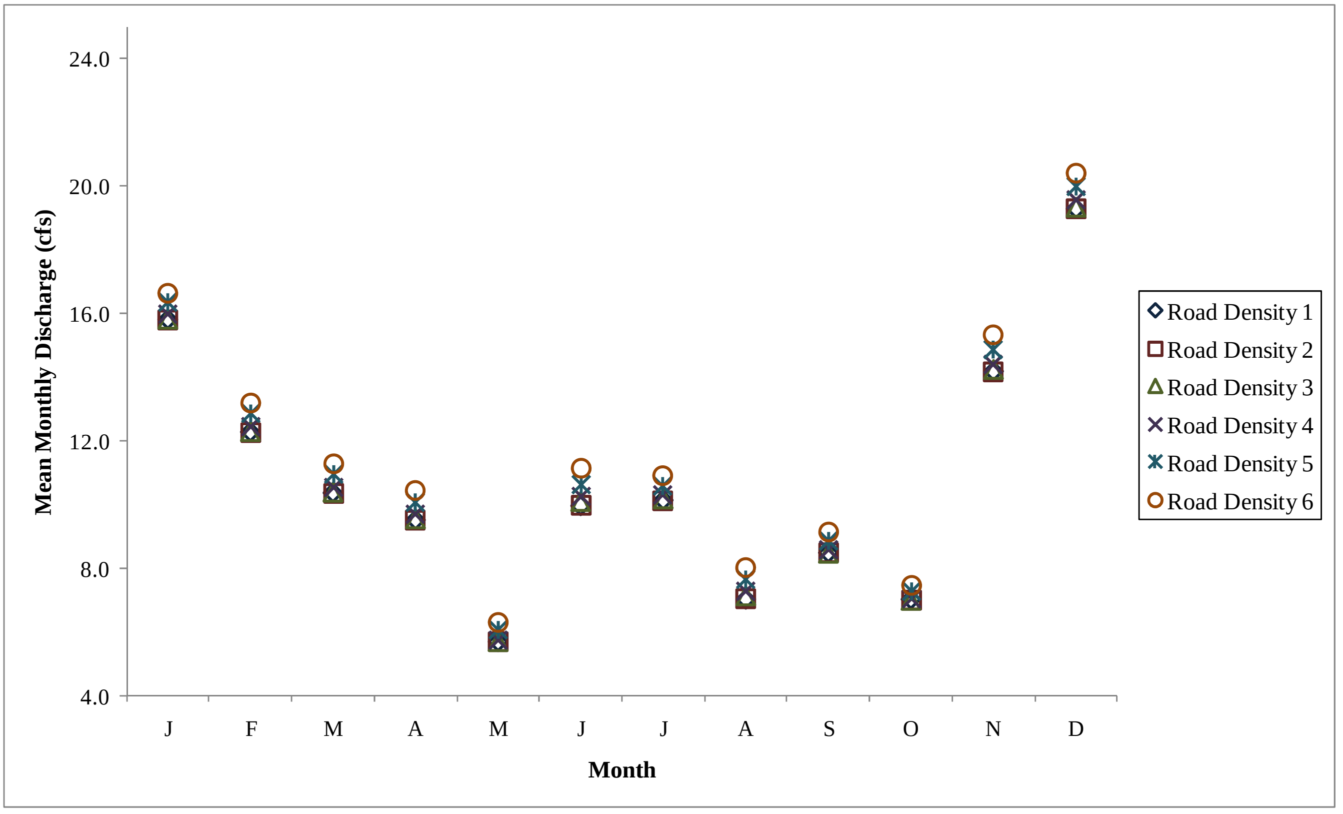

Figure 3 Shope Fork mean monthly discharge averaged over four-year study period. Road density 1 = 0.8 mi mi^{-2}; Road density 2 = 1.6 mi mi^{-2}; Road density 3 = 4.8 mi mi^{-2}; Road density 4 = 6.9 mi mi^{-2}; Road density 5 = 9.7 mi mi^{-2}; Road density 6 = 19.3 mi mi^{-2}

Table 3 Tukey-Kramer test results for significant difference between treatments for monthly and average monthly data.

Treatment	1	2	3	4	5	6
1		NS	NS	S	S*	S*
2	NS		NS	S	S*	S*
3	NS	NS		NS	S*	S*
4	S	S	NS		S*	S*
5	S*	S*	S*	S*		S*
6	S*	S*	S*	S*	S*	

NS: No significant difference between treatments; S: significant difference at $\alpha = 0.01$; S*: significant difference at $\alpha < 0.0001$

Summary and Conclusions

Calibrating a distributed hydrology model for use in forested watersheds in the Blue Ridge Mountains was met with moderate success. The calibrated period (Water Year 2004) had model accuracy (R^2) of 0.48 while the three-year validation period (Water Years 2005-2007) had a higher overall accuracy of 0.73. These values should be considered successful, as DHSVM was designed for use in mountainous terrains and has primarily been applied to studies in the Pacific

Northwest (Beckers and Alila, 2004; Bowling and Lettenmaier, 2001; Lamarche and Lettenmaier, 1998).

Despite the successes, there was still a large amount of unexplained variance in the calibration of DHSVM for the Shope Fork catchment. Such errors could be attributed to the following factors: (1) the difference in terrain and climate regime between typical model research applications and the study site; (2) errors in peak flow and baseflow modeling due to the lack of preferential flow pathways in the model; (3) user error while preparing the model for use; and (4) error in data input as a result of over-parameterization of the model. DHSVM also requires numerous input parameters and this study was conducted using little to no field collected data. Accuracy might be improved with field sampling, and a sensitivity analysis could be used to determine what parameters would be worth collecting.

Using DHSVM as a relatively controlled environment, we were able to model the impacts of road density on stream discharge. This process was complex, as road density is not independent from other road features and confounding effects were present. Although we attempted to account for confounding effects, we realize that they are a constraint in the study. The modeled results suggest that mean monthly stream discharge will be impacted when forested road density reaches and surpasses 6.9 mi mi^{-2}. The effects on streamflow in this watershed are thought to be a function of intercepted subsurface flow and increased runoff on the road surfaces, both of which have been shown to increase streamflow in forested areas with roads (Ziemer, 1981; Jones, 2000). In order to minimize impacts on stream discharge, forest managers should aim to keep road densities below this 6.9 mi mi^{-2} threshold and allow for careful planning throughout all phases of road construction.

Literature Cited

Beckers, J. and Y. Alila. 2004. A model of rapid preferential hillslope runoff contributions to peak flow generation in a temperate rain forest watershed. *Water Resources Research* 40.

Bernard, A. M. 2006. *Geospatial Modeling of Forest Road Networks and Their Effects on Stream Macroinvertebrate Communities*. M.Sc. Virginia Polytechnic Institute and State University. Blacksburg, VA.

Bowling, L. C. and D. P. Lettenmaier. 1997. *Evaluation of the Effects of Forest Roads on Streamflow in Hard and Ware Creeks, Washington*. University of Washington Water Resources Series 155. 202 p.

Bowling, L. C., P. Storck, and D.P. Lettenmaier. 2000. Hydrologic effects of logging in western Washington, United States. *Water Resources Research.* 36(11): 3223-3240.

Cornish, P.M. and R.A. Vertessy. 2001. Forest age-induced changes in evapotranspiration and water yield in a eucalypt forest. *Journal of Hydrology*. 242: 43-63.

Coweeta LTER. 2008. COGENT: GIS Data. *National Science Foundation*. Available online at: http://coweeta.uga.edu/ecology/cogent.html; last accessed Jan. 2008.

Cuo, L., T. W. Giambelluca, A.D. Ziegler, and M.A. Nullet. 2006. Use of the distributed hydrology soil vegetation model to study road effects on hydrological processes in Pang Khum Experimental Watershed, northern Thailand. *Forest Ecology and Management.* 224: 81-94.

Day, F. P., Jr., D. L. Phillips, and C.D. Monk. 1988. Forest Communities and Patterns. P. 141-149 in *Forestry Hydrology and Ecology at Coweeta*. W. T. Swank and D. A. Crosley, Jr. (eds.). Springer-Verlag, New York, New York.

Doten, C.O., L.C. Bowling, J.S. Lanini, E.P. Maurer, and D.P. Lettenmaier. 2006. A spatially distributed model for the dynamic prediction of sediment erosion and transport in mountainous forested watersheds. *Water Resources Research.* 42.

Douglass, J. E. and M. D. Hoover. 1988. History of Coweeta. P. 17-31 in *Forestry Hydrology and Ecology at Coweeta*. W. T. Swank and D. A. Crosley, Jr. (eds.). Springer-Verlag, New York, New York.

Forman, R. T. 2000. Estimate of the area affected ecologically by the road system in the United States. *Conservation Biology*. 14(1): 31-35.

GeoCommunity. 2007. GIS Data Depot. *GeoCommunity*. Available online at: http://data.geocomm.com.

Hawbaker, T. J., V. C. Radeloff, R.B. Hammer, and M.K. Clayton. 2005. Road density and landscape pattern in relation to housing density, land ownership, land cover, and soils. *Landscape Ecology*. 20: 609-625.

Hewlett, J.D. and J.D. Helvey. 1970. Effects of forest clear-felling on the storm hydrograph. *Water Resources Research.* 6: 768-782.

Hillier, A., 2007. ArcGIS 9.3 Manual. *Environmental Systems Research Institute*. Available online at: http://works.bepress.com/amy_hillier/17.

Hornbeck, J. W., R. S. Pierce, and C.A. Federer. 1970. Streamflow changes after forest clearing in New England. *Water Resources Research.* 6: 1124-1132.

Jones, J. A. 2000. Hydrologic processes and peak discharge response to forest removal, regrowth, and roads in 10 small experimental basins, western Cascades, Oregon. *Water Resources Research.* 36: 2621-2642.

La Marche, J.L. and D.P. Lettenmaier. 2001. Effects of forest roads on flood flows in the Deschutes River, Washington. *Earth Surface Processes and Landforms*. 26: 115-134.

Leung, L. R., M. S. Wigmosta, S.J. Ghan, D.J. Epstein, and L.W. Vail. 1996. Application of a subgrid orographic precipitation/surface hydrology scheme to a mountain watershed. *Journal of Geophysical Research.* 101(D8): 12803-12817.

Nash, J. E. and J. V. Sutcliffe. 1970. River flow forecasting through conceptual models: Part I-A discussion of principles. *Journal of Hydrology.* 10: 282-290.

National Forests in North Carolina: Fiscal Year 2007. 2008. USDA Forest Service. Ashville, NC.

Pielke, Jr., R.A., J. Gratz, C.W. Landsea, D. Collins, M.A. Saunders, R. Musulin. 2008. Normalized hurricane damage in the United States: 1900-2005. *Natural Hazards Review*. 9(1): 29-42.

Soil Survey Staff. 2008. U.S. General Soil Map (SSURGO) for Macon County, North Carolina. *USDA Natural Resour. Conserv. Serv.* Available online at http://soildatamart.nrcs.usda.gov.

Storck, P., L. Bowling, P. Weatherbee, and D. Lettenmaier.1998. Application of a GIS-based distributed hydrology model for prediction of forest harvest effects on peak stream flow in the Pacific Northwest. *Hydrological Processes*. 12: 889-904.

Swank, W. T. and D. A. Crosley, Jr. 1988. Introduction and Site Description. P. 3-16 in *Forest Hydrology and Ecology at Coweeta*. W. T. Swank and D. A. Crosley, Jr. (eds.). Springer-Verlag, New York, New York.

Swank, W. T., J. M. Vose, and K.J. Elliott. 2001. Long-term hydrologic and water quality responses following commercial clearcutting of mixed hardwoods on a southern Appalachian catchment. *Forest Ecology and Management.* 143: 163-178.

Swift, L. W., Jr., G. B. Cunningham, and J.B. Douglass. 1988. Climatology and Hydrology. P. 35-55 in *Forest Hydrology and Ecology at Coweeta*. W. T. Swank and D. A. Crosley, Jr. (eds.). Springer-Verlag, New York, New York.

Thomas, D. J., T. N. Vrana, H.O. Schmitt, W.T. Schaefer, and S.A. Browning. 1996. *Soil Survey of Macon County, North Carolina*. US NRCS. U.S. Goverment Printing Office. 322 p.

Thyer, M., J. Beckers, D. Spittlehouse, Y. Alila, and R. Winkler. 2004. Diagnosing a distributed hydrologic model for two high-elevation forested catchments based on detailed stand- and basin-scale data. *Water Resources Research.* 40:20.

VanShaar, J.R., I. Haddeland, and D.P. Lettenmaier. 2002. Effects of land-cover change on the hydrological response of interior Columbia River basin forested catchments. *Hydrolgical Process.* 16: 2499-2520.

Wigmosta, M. S., L. W. Vail, and D.P. Lettenmaier. 1994. A distributed hydrology-vegetation model for complex terrain. *Water Resour. Res.* 30:1665-1679.

Wigmosta, M. S. and S. J. Burges. 1997. An adaptive modeling and monitoring approach to describe the hydrologic behavior of small catchments. *Journal of Hydrology.* 202: 48-77.

Wigmosta, M. S. and D. P. Lettenmaier. 1999. A comparison of simplified methods for routing topographically driven subsurface flow. *Water Resour. Res.* 35(1):255-264.

Wigmosta, M. S., B. Nijssen, and P. Storck. 2002. The Distributed Hydrology Soil Vegetation Model. P 7-42 in *Mathematical Models of Small Watershed Hydrology and Applications*. V. P. Singh and D. Frevert. Water Resources Publications.

Ziemer, R. 1981. Storm flow response to road building and partial cutting in small streams of Northern California. *Water Resources Research.* 17(4): 907-917.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Status of Harvesting & Transportation for Forest Biomass – Preliminary Results of a National Survey of Logging Contractors, Procurement Foresters, Wood Dealers and Forest Managers

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ABSTRACT

As US and international policy moves toward the use of bioenergy, the forest sector is actively adapting wood procurement systems and management regimes to accommodate an emerging market. The harvesting and transportation of biomass material as a feedstock for the forest products and energy industries is a potential growth area. The need for cost effective and productive supply logistics is forcing the industry to develop technology and adjust traditional utilization rates to increase recovery from the forest resource. An online national survey was conducted to evaluate current wood procurement systems and harvesting technology to provide a measure of the current biomass market. Participation in the survey included logging contractors, procurement foresters, wood dealers and forest managers with representation throughout six geographic regions, covering the contiguous 48 states.

INTRODUCTION

Today, renewable energy provides about 7% of the total US energy use with roughly half coming from biomass sources (75% of which comes from forests). Most forest biomass is burned to produce heat and/or electricity for the forest products industry and the grid. Wood pellet markets are driven primarily by coal-fired electric plants in the European Union. Most major US utilities and several independent electricity producers have announced plans to build new energy capacity, based on wood as a feedstock.

Recent introduced climate change legislation in the US has included ambitious federal renewable electricity standards of 20% by 2020 or 25% by 2025. The renewable liquid fuel standard passed in the 2007 energy bill set a target of 36 billion gallons of renewable liquid fuels by 2022 (28 billion gallons from cellulosic sources). The "Billion Ton Report" prepared by the Department of Energy and Agriculture in 2005 suggests that 1 billion dry tons of biomass can be sustainably produced in the US with 37% coming from forests (Perlack *et al.* 2005). Producing 370 million dry tons from forests would imply a doubling of current US timber harvest levels (Sample 2009).

A globally competitive wood supply system is already in place in the United States, producing traditional products such as pulpwood, sawtimber, and clean chips. As resource and procurement managers grapple with policy and market forces, existing supply chain logistic models are being evaluated to identify ways to recover additional value through biomass. Capturing waste and residue from traditional roundwood harvesting and production processes is the first step towards bioenergy targets. Markets are developing for wood pellets and electricity from wood.

The harvest of additional biomass requires modifications to forest management regimes, harvest systems, and technology to obtain this material productively and economically with minimal impacts to harvest sites. Cost effective harvesting and transportation are keys to delivering quality biomass feedstock at a competitive market price (Aguilar and Garnett 2009). How is the forest sector dealing with these challenges? This project assessed the current state of biomass harvesting and transportation systems throughout the US including an evaluation of traditional logging systems and independent logistic systems specifically tailored to biomass harvesting.

This project assessed the current state of biomass harvesting and transportation systems throughout the US. We evaluated traditional logging and transportation systems and their modifications to improve utilization and increase recovery for forest biomass. Independent logistic systems specifically tailored to biomass harvesting were also evaluated to gauge supply implications.

METHODS

We targeted active participants in the wood supply system for participation in an online survey that was available during April and May of 2010. The survey assessed the state of biomass harvesting, collection, and transportation technology currently used across the US. Distribution of the survey was not conducted as a random sample but rather by choosing respondents purposefully. Member companies and logging associations of the Wood Supply Research Institute were contacted and asked to forward an email describing the survey to members of their organizations. Companies that purchase wood were asked to have their procurement managers responsible for manufacturing facilities complete the survey. Land management firms were asked to have their region managers complete the survey. Logging associations were asked to forward the survey to all logging contractor and wood dealer members.

Upon accessing the survey, each respondent was asked to identify themselves as a land management forester, procurement forester, logging contractor, or wood dealer (Figure 1). Every survey participant was asked a set of common questions. In addition, role-specific questions were asked to obtain information from the perspective of different players in the wood supply chain. Questions sought information on product forms, haul distances, minimum recoverable biomass amounts per acre and per tract, market requirements for product quality, and other variables to understand the sensitivity of cost effective operations. Geographically, the country was divided into six regional units based upon the regions used by the Forest Resources Association (Figure 2). One reminder was sent out after about two weeks with a second reminder sent about two weeks later. The survey was available for completion from April 6 to May 18, 2010.

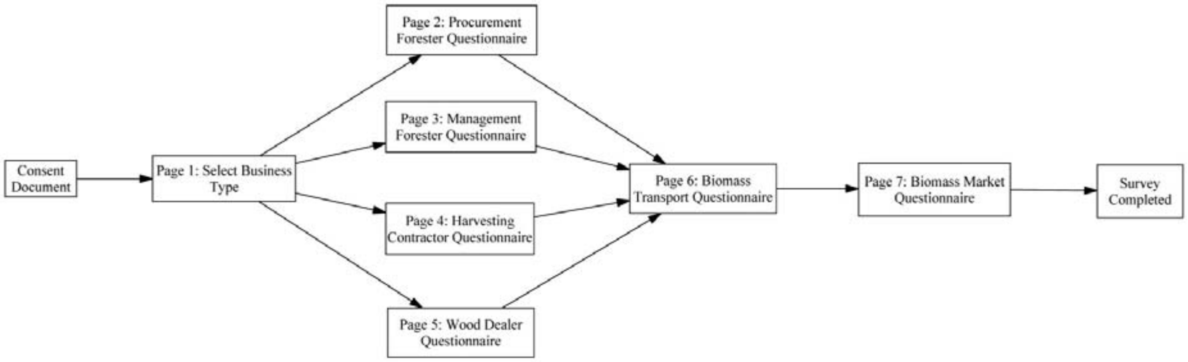

Figure 1. Flow chart illustration the progression of the online survey to identify factors associated with forest biomass harvest, collection, and use.

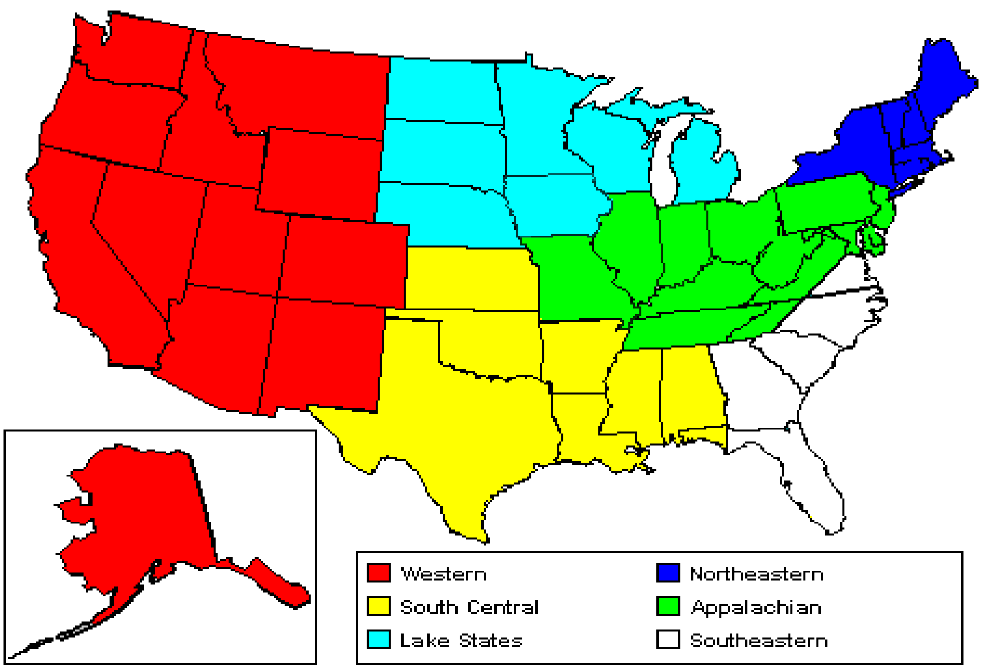

Figure 2. US forest regions as defined by the Forest Resources Association.

PRELIMINARY RESULTS

We present preliminary results based upon data collected through May 12, 2010. Participation for the survey was greatest for the South Central, Southeastern, and Lake States regions (Figure 3). Harvesting contractors were the largest respondent group in most regions, which was desired and a reason for the method of survey delivery. All logging associations throughout the country were contacted, whereas only WSRI member companies were contacted for participation.

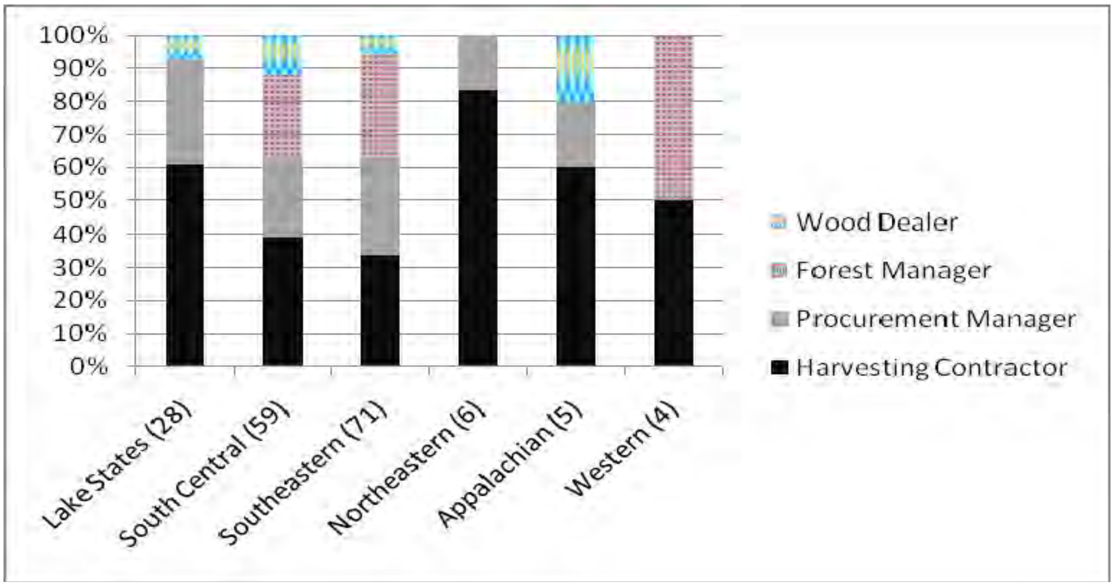

Figure 3. Participation in the biomass survey by region of the country and functional role in the industry. Numbers in parentheses indicate total responses within the region.

Among wood dealers, harvesting contractors, and procurement foresters, 60% reported producing or selling biomass whereas around 80% of forest managers indicated that they are selling biomass. Preliminary results of the online survey indicate dirty wood chips are sold as the favored primary feedstock followed by unscreened grindings and roundwood (Figure 4). The prevalence of roundwood, and to a lesser extent clean chips, indicate that biomass markets are already beginning to utilize "traditional" forest product feedstocks for supply. The reported frequency of clean chips, screened grindings, and roundwood (35%) also indicates reluctance in some markets to use "dirty" products such as whole-tree chips and unscreened grindings. Bundles and bales were offered as a feedstock type, but were not selected by any participants.

By far the most popular (59%) method of harvesting biomass materials was during conventional harvesting (Figure 5). The majority of biomass operations deployed wheeled feller-bunchers and skidders with pull-through delimbers/loaders at landings. Given the large response from the southern states where such systems are dominant, this is not surprising. Logging contractors' choice of grinding or chipping equipment was roughly equal (30% each) for drum chippers, disk chippers, and horizontal grinders with no bundlers/balers and few tub grinders represented in the survey.

An average requirement of 20 tons per acre of biomass material was listed by harvesting contractors and procurement foresters as the economic minimum to justify harvesting, but this appears to vary depending on stand type, purpose of treatment, and scale of operation. Forest managers surveyed reported an average of 13 tons per acre as the economic minimum. Minimum tonnage on a single tract or sale was highest for logging contractors at 1255 tons and lowest for forest managers presenting 680 tons. This variation likely results from a difference in objectives as logging contractors attempt to minimize unit costs ($/ton) while forest managers are trying to maximize value per acre.

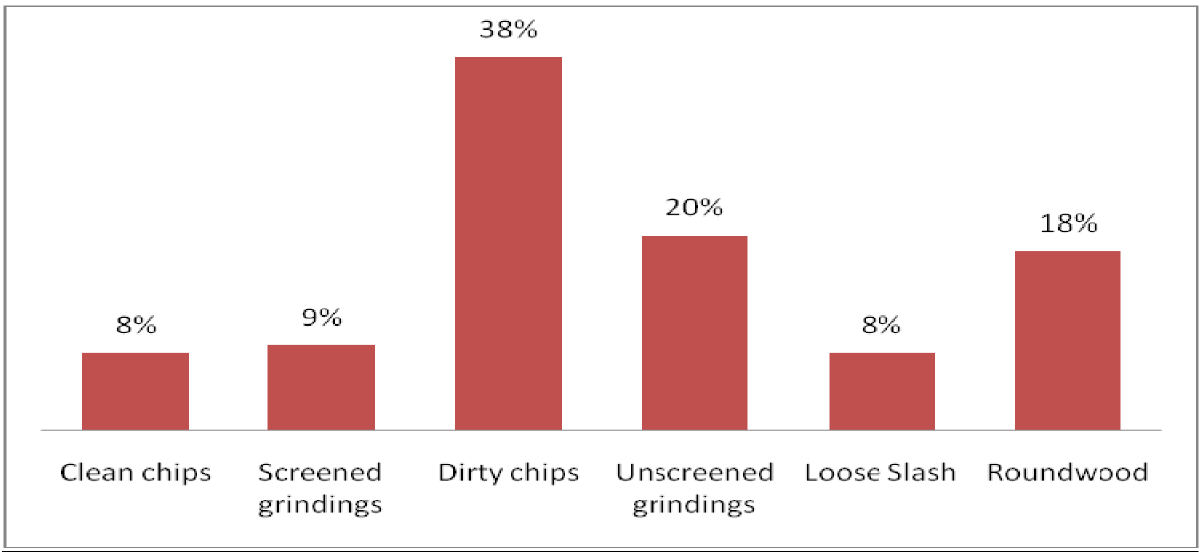

Figure 4. Types of forest biomass feedstock delivered to markets across the US.

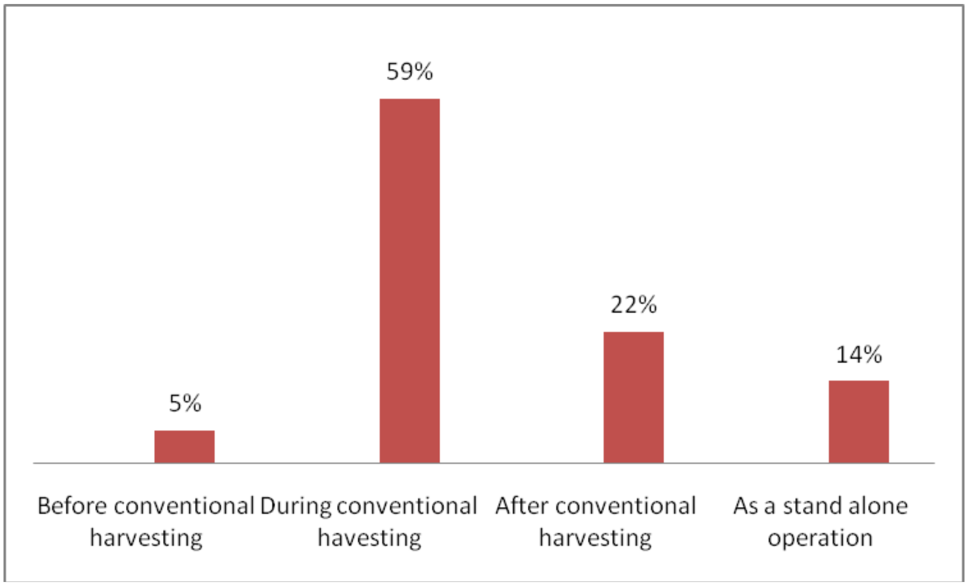

Figure 5. Timing of biomass harvesting/collection and its relation to other harvests.

Distance to market is an important economic factor for low-value products such as biomass. A majority of respondents (56%) reported an average haul distance between 31-50 miles with another 24% indicating hauls of 51-70 miles (Figure 6). Only 8% reported distances of greater than 70 miles while 12% indicated their markets were less than 30 miles away on average.

Payload is another key transportation factor that can mitigate the impact of long haul distances and must be maximized if delivered costs are to be competitive. Nearly half (47%) of our survey respondents indicated that their payload was in the 26-28 ton range with another 34% suggesting 23-25 tons (Figure 7). These payloads compare favorably to those common with roundwood and conventional chip products. This is not unexpected given the product forms reported earlier for biomass.

Another key transportation efficiency factor is the time it takes trucks to get unloaded at a receiving facility. Our survey thus far finds turn-around times of less than 30 minutes or 31-45 minutes reported by 33% and 44% of respondents respectively (Figure 8). These times are comparable to those commonly reported for traditional forest products as well.

Nearly half (49%) of those responding reported delivering biomass feedstocks to pulp mills (Figure 9). No other market was reported by more than 15% of those taking the survey. This clearly indicated that the most widespread market for biomass today is the pulp industry, with other markets much less widespread. No respondents reported biomass sales to or purchases for a liquid fuels facility.

Half of the people surveyed indicated that a biomass facility was under construction in their region. Forty percent of respondents indicated that the biomass markets were growing in their area (Figure 10). Nearly as many (38%) reported that such markets were “inconsistent”. There was no clear message on the status of biomass markets. A slight majority (52%) reported them as “growing” or “stable” while 48% listed them as “inconsistent”, “in decline”, or “non-existent". Biomass markets are poised to increase in the near future, but much of this growth to date appears to be localized. Only one in four respondents feel that greater biomass harvesting will increase future roundwood supplies in their area, compared to 42% who feel it will lead to a decline (Figure 11).

SUMMARY

Preliminary results of the online survey describe basic parameters for harvesting operations and transportation logistics. Harvesting and transportation trends are outlined to understand the current state the biomass markets. Pulp mills and forest product facilities have been identified as the largest consumers of biomass feedstocks with fifty eight percent sold as dirty chips or unscreened grindings. The most common form of biomass recovery occurs in conjunction with conventional harvesting with the use of drum chippers, disc chippers or horizontal grinders. Transportation parameters such as average haul distance of 31-50 miles and average payload of 26-28 tons are reported as market indicators for trucking. An analysis of trends by region will be forthcoming after the collection phase of the project is concluded.

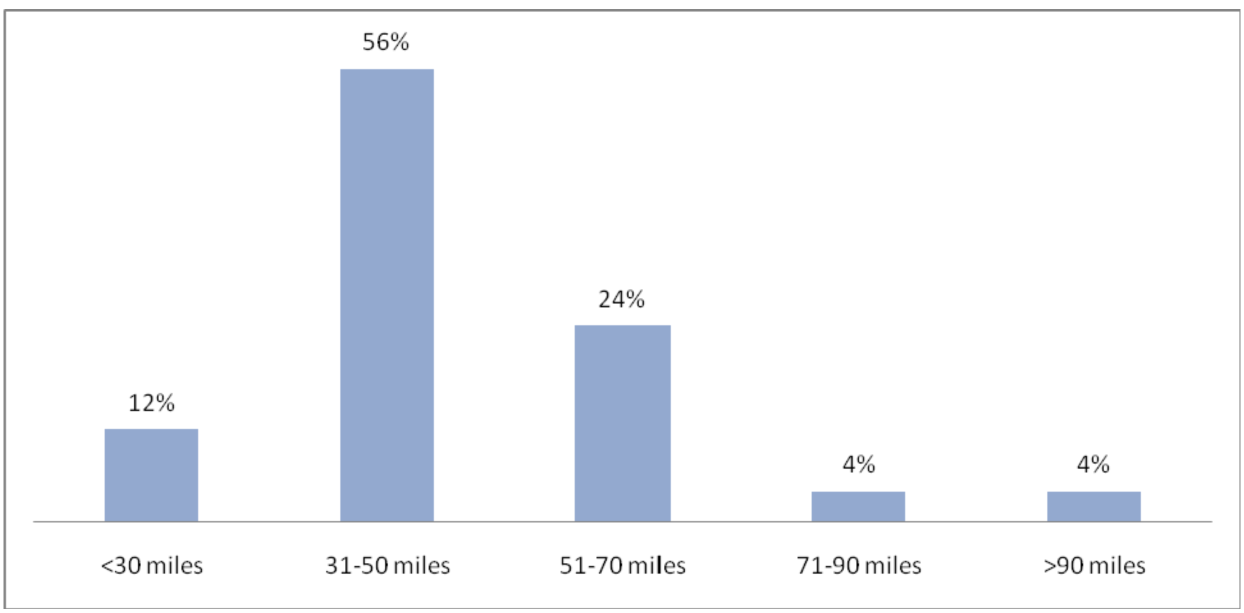

Figure 6. Average haul distance of forest biomass reported by survey respondents across the US.

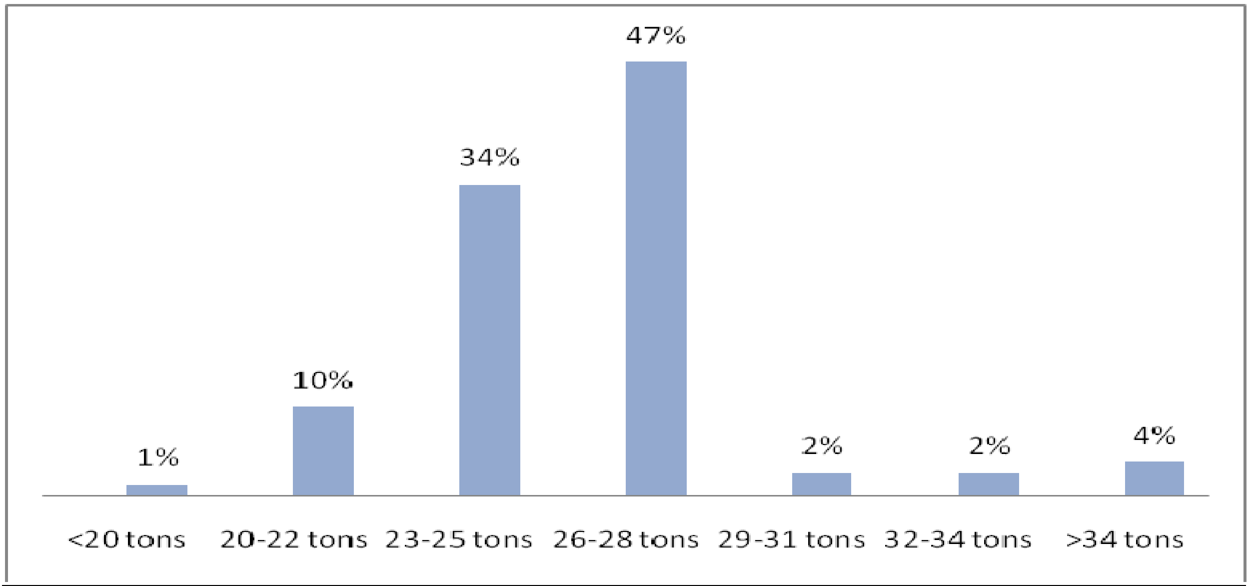

Figure 7. Average payload for biomass transportation reported across the US.

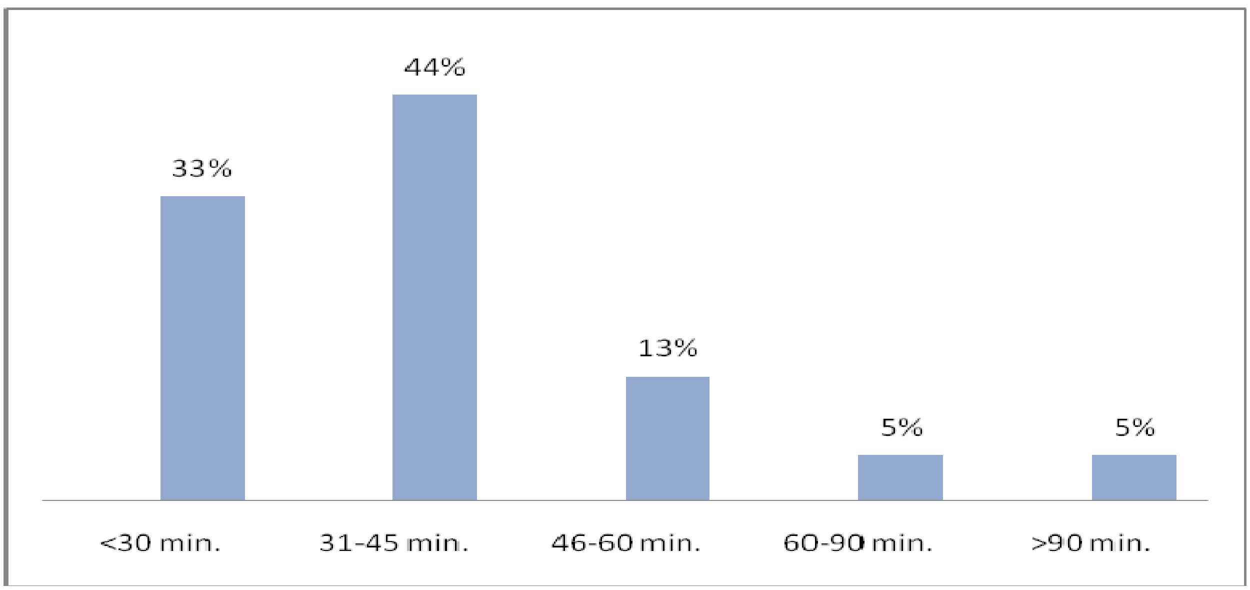

Figure 8. Reported average turnaround times at the receiving mill for trucks transporting biomass across the US.

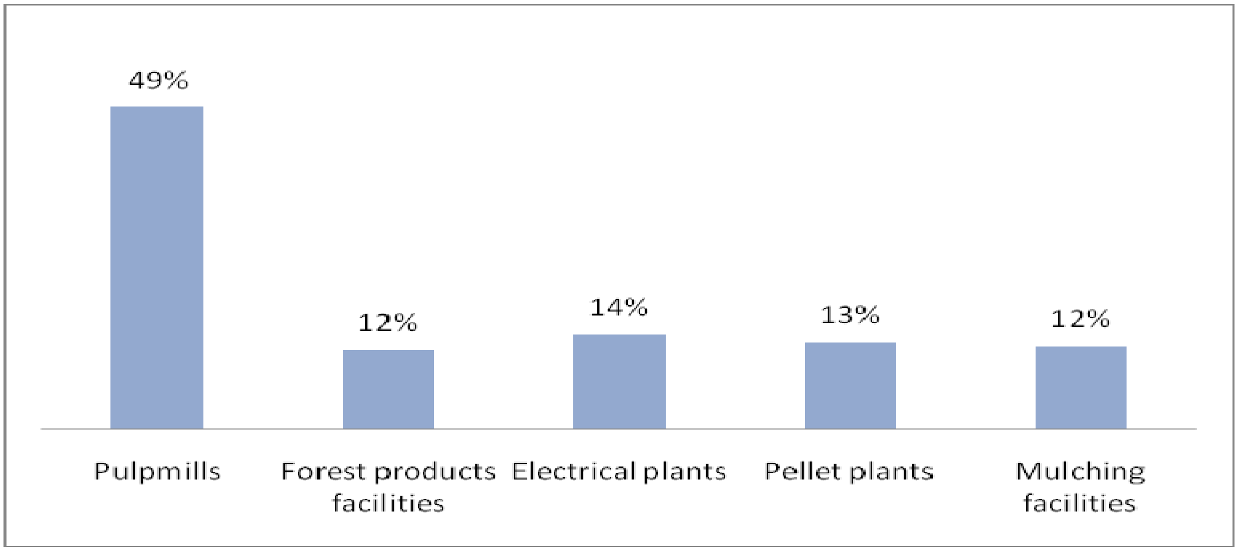

Figure 9. Types of mills receiving forest biomass reported by survey respondents across the US.

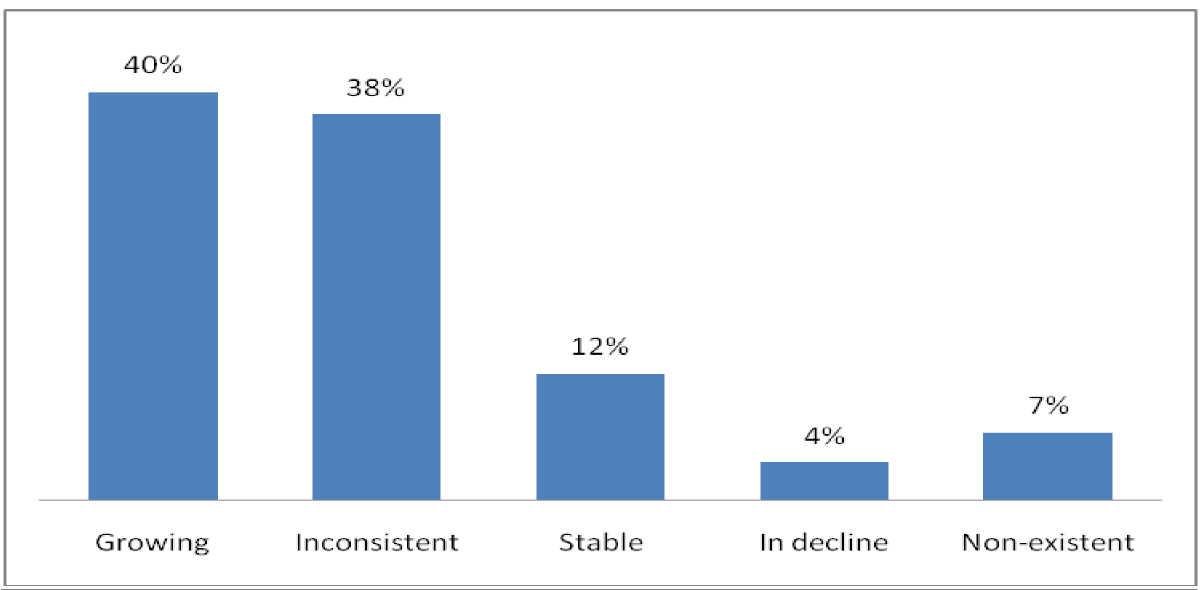

Figure 10. Respondent opinions of the current status of biomass markets in their area.

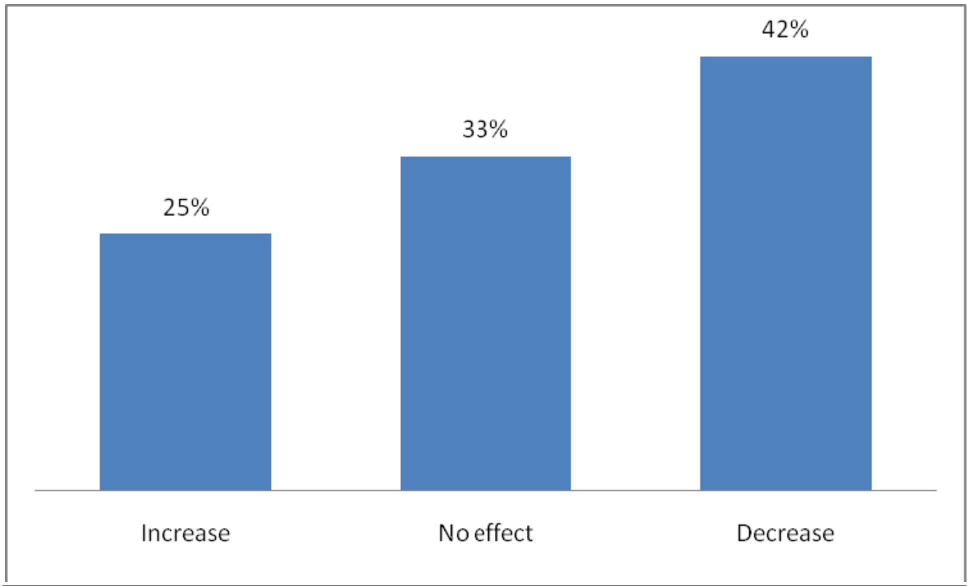

Figure 11. Respondent opinions of the potential impact of biomass harvesting on future roundwood supply in their area.

ACKNOWLEDGEMENTS

Funding for this project was provided by the Wood Supply Research Institute. We thank the American Loggers Council for their assistance with this project.

LITERATURE CITED

Aguilar, F. and H.E. Garrett. 2009. Perspectives of woody biomass for energy: survey of state foresters, state energy biomass contacts, and national Council of Forestry Association Executives. J. For. 107(6): 297-306.

Perlack, R.D., L.L. Wright, A.F. Turhollow, R.L. Graham, B.J. Stokes, and D.C. Erbach. 2005. Biomass as feedstock for bioenergy and bioproducts industry: the technical feasibility of a Billion-ton annual supply. US Dept. of Energy and Dept. of Agric. report. 64 p.

Sample, V.A. 2009. Summary/synthesis: What Role Will Forests Play in America's Long-Term Energy Future? Pinchot Institute for Conservation. 26p.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Development of a Correlation Equation between Clegg Impact Values and California Bearing Ratio for In-Field Strength Assessment of Forest Road Subgrades

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In-field strength assessment of forest road subgrades is useful for pavement design and for quality control of road construction. Many instruments and test methods are available for such assessments; however, technical road engineering limitations and economic constraints within the forest industry require test methods that are low cost, portable and easy to implement and interpret. The Clegg Impact Soil Tester (CIST) is an instrument that meets these criteria.

Interpretation of CIST test results requires the development of equations to correlate the resulting Clegg Impact Values (CIV) to the California Bearing Ratio (CBR) – a widely accepted measure of subgrade strength. A number of equations exist to convert CIV to CBR; however, these equations have been developed using materials ranging from weak subgrades through to high-strength pavement surfaces not typically used on forest roads. A correlation equation developed specifically for forest road subgrades is desired to improve the ability of the CIST to predict subgrade CBR values.

This study involved the collection of subgrade soil samples from forest roads located throughout the commercial forest estate in the East Cape region of New Zealand. The soil samples were prepared at various moisture contents and tested in the laboratory to establish paired CIV and CBR values. Other soil properties, including plasticity, soil classification, maximum dry density and optimum moisture content, were evaluated to assess the effect that these properties may have on the CIV to CBR correlation.

The analysis indicates a relatively strong correlation between CIV and CBR for forest subgrade soils. Clayey and excessively wet soils have a significant negative impact on the correlation. This study shows that, while the CIV to CBR correlation is not highly accurate, the simplicity and efficiency of the CIST makes it an effective tool to promote a greater understanding of subgrade bearing strength. Improved accuracy may be achieved by taking and averaging multiple CIST readings.

Introduction

Forestry road building in New Zealand varies widely across regions, where each region faces their own unique set of issues, problems and benefits. The East Cape of New Zealand is an area where road building is problematic. The combination of steep terrain, lack of quality aggregate (road surfacing material), and the long haul distances associated with transporting the sub-optimal aggregate makes road building and maintenance more costly than in other regions. In the East Cape region, the cost of purchasing and transporting aggregate is expensive, contributing up to 80% of total road construction cost.

The cost of aggregate can be reduced by improving the native soil, known as the subgrade, so that less aggregate is required. Improvement can be achieved through many methods, such as chemical stabilisation, compaction and water content management; however, subgrade improvement requires an effective method of testing subgrade strength in the field. A test instrument suitable for low volume roads is the Clegg Impact Soil Tester (CIST) – a lightweight, low-cost and rapid in-field soil strength tester. The CIST was developed by Dr. Baden Clegg of the University of Western Australia in the late 1970s for the evaluation of subgrade soil strength (Clegg 1976). It was designed to be used in place of the more onerous California Bearing Ratio (CBR) test. The CIST primarily consists of a drop weight, a guide tube for the weight, and an accelerometer, as shown in Figure 1. The CIST measures the deceleration of the 4.5kg drop weight when it comes into contact with the soil from a height of 450mm. A relative measure of pavement strength, the Clegg Impact Value (CIV), is given where a value of 1 is equal to a peak instantaneous deceleration of 10 gravities. The test typically takes less than 1 minute to perform and can be carried out by an operator that has minimal training.

Figures 1a and 1b: The Clegg Impact Soil Tester (left) and the CIST being used to test the subgrade of an East Cape forest road (right).

This study examines the use of the CIST for testing East Cape subgrade soils. Subgrade samples from the region were collected and tested in the lab to develop a CIV to CBR correlation. The accepted approach for developing this correlation is to do paired testing of soils in the laboratory environment using standard CBR and CIV test methods. A number of studies have been published on the merit of such correlations (Al-Amoudi *et al.,* 2002, Pidwerbesky 1997, Mather & Coghlans 1987, Clegg 1978). These studies have reached wide ranging conclusions, from the positive "The CIV data correlated exponentially well with the CBR results" (Al-Amoudi *et al.,* 2002), to a paper by Pidwerbesky (1997) which concludes "The Clegg Hammer had serious deficiencies when compared with the other devices. There is no evident correlation or trend against which quality control parameters could be confidently set." More descriptive results were given by Gulen & McDaniel (1990) who analysed the use of the CIST for eleven different soils and concluded that the CIST struggles to predict soil bearing strength in sandy soils and also when the soils are saturated.

Four published CIV to CBR correlation equations are presented in Figure 2. These correlation equations were developed using data points for soils and aggregates over a CBR range of 1 to 250; however a subgrade CBR exceeding 30 is irrelevant for forest road design since minimum aggregate thickness for an unsealed pavement (typically 100mm) is achieved if CBR is greater than 30. The effect of including higher CBR values when determining a correlation equation is that these high values can bias the regression. This study focuses on developing a correlation equation specifically for East Cape subgrade soils, which typically have CBR values less than 30.

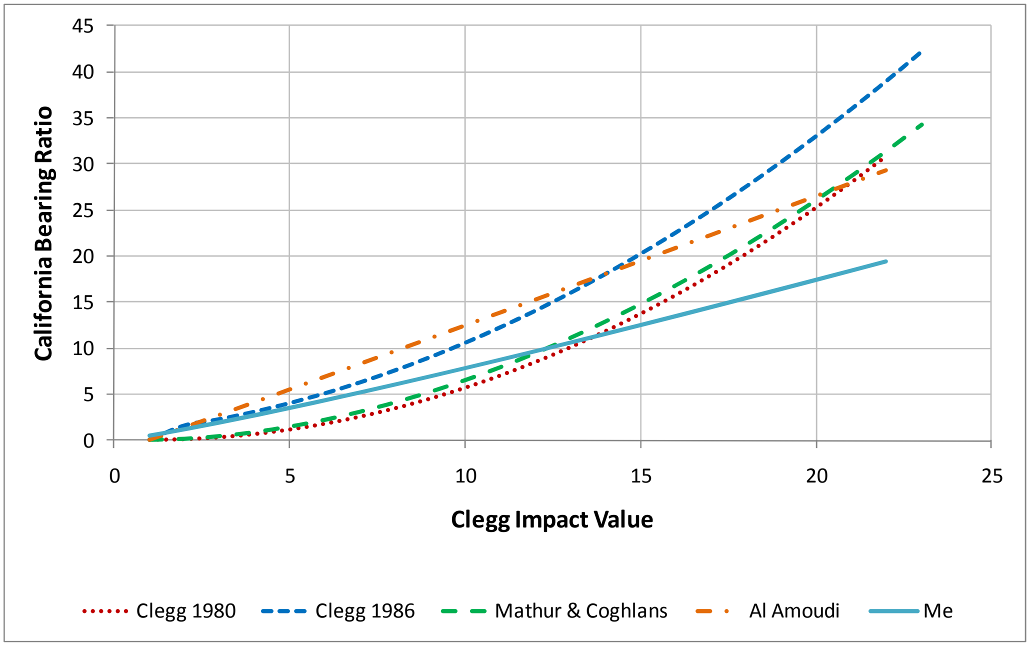

Figure 2: CIV to CBR correlations (Clegg 1976, 1980), (Mathur & Coghlans 1987), (Al-Amoudi et al. 2002).

Examination of the correlations in Figure 2 shows that significantly different CBR values are estimated, depending on which correlation equation is used. For example, a CIV=10 could correlate to a low CBR=5 if using the Clegg 1980 correlation or a high CBR=13 if using the Al Amoudi correlation. From a pavement design perspective, this variation could result in pavement thickness being over-designed (and thus excessively expensive) or under-designed and potentially failing.

The consequence of the variability between correlations is that Clegg has recommended that each organisation should consider establishing its own relationship for specific materials and conditions, particularly where there is strong reliance on CBR for design purposes (Clegg 1986).

Method

Seventeen soil samples were collected from six different forests in the East Cape region of New Zealand. These samples were analysed in the laboratory using the following tests: particle size distribution, dry density/water content relationship, liquid limit, plastic limit, plastic index and the CBR test. These tests were conducted in accordance with the procedures in NZS 4402:1986: Methods of testing soils for civil engineering purposes (Standards NZ, 1986). The CIST test was conducted in accordance with the test procedure outlined in the CIST/883 Clegg impact soil tester operators' manual Ver. 1.14b4b-AU.

Results

The particle size distribution tests indicate that the 17 soils used for this study belong to six general soil types, as shown in Figure 3, ranging from lean clay through to silty sand with gravel.

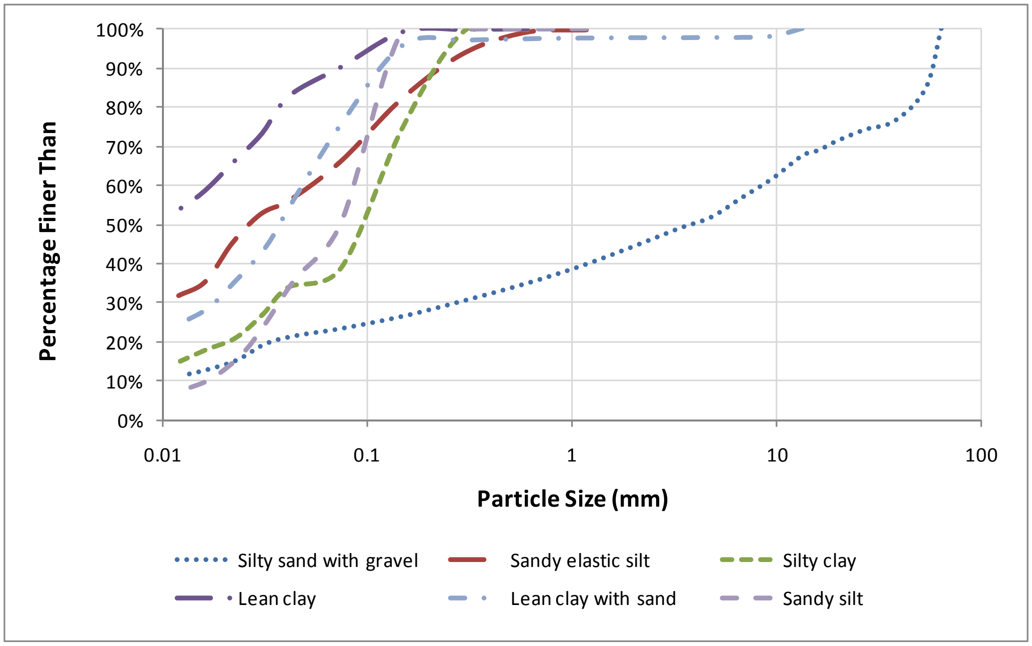

Figure 3: Particle size distribution test results for East Cape subgrade soils.

The dry density/water content relationship test is used to determine the optimum water content at which to compact each soil. Each soil produced a curve similar to Figure 4, with dry density peaking at optimum water content (OMC).

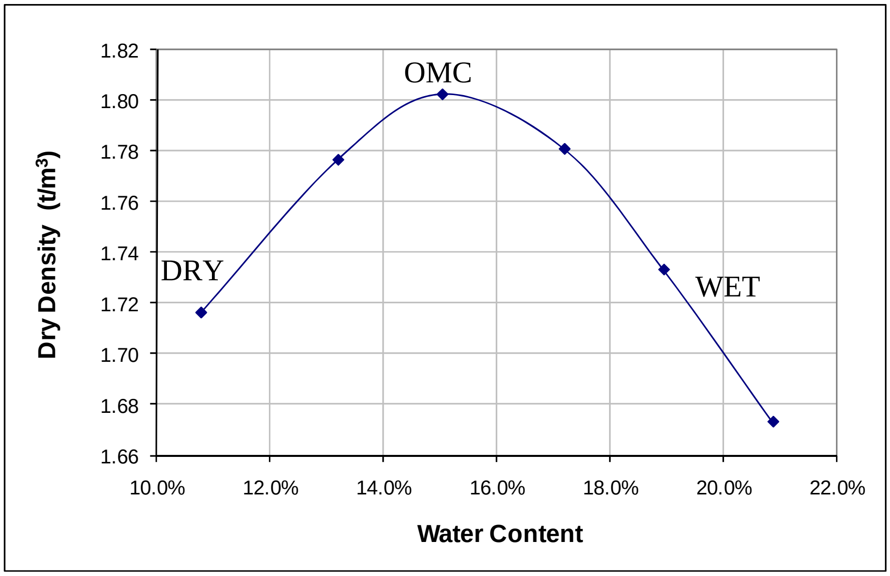

Figure 4: Dry density/water content relationship test results for Soil #11

The CIV and CBR paired test results are presented as Figure 5. The key finding from these results were that the data is reasonably well correlated with an R^2=0.70. By comparison, the correlation equations in Figure 2 have R^2 ranging from 0.79 to 0.92. The reason for the lower coefficient of determination for this study is most likely due to the smaller data set and absence of higher CBR values to bias the correlation. The main limitation of these results is that while CIV is a reasonable predictor for CBR over the dataset, it is a relatively poor predictor for single data points. For example, a CIV=8 from these results could indicate a CBR ranging anywhere from 1-8. This is an unsatisfactory result, since soils with CBR<3 are considered unfit for road construction without soil modification or use of reinforcing material, whereas a CBR=8 represents a reasonably competent subgrade layer.

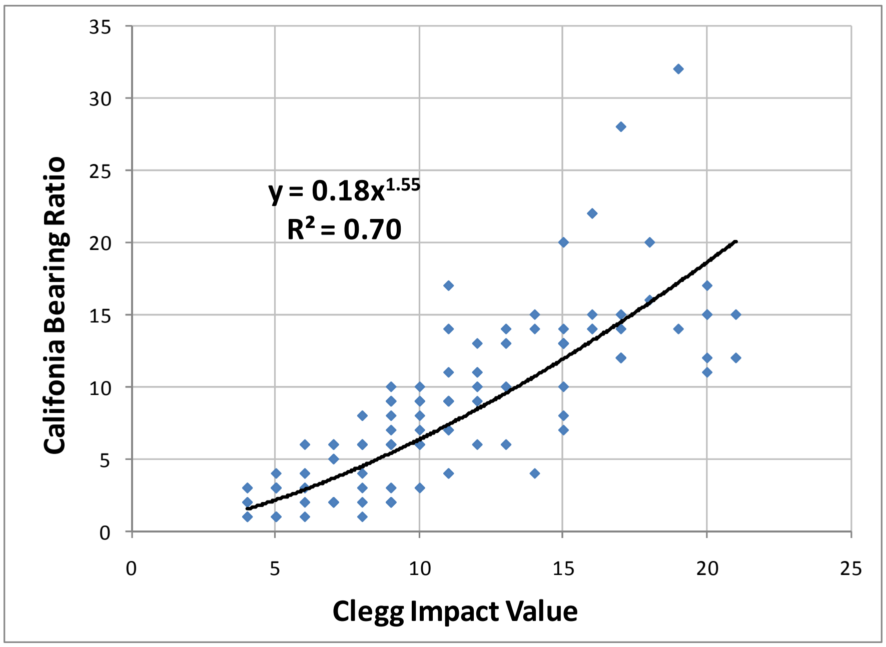

Figure 5: CIV to CBR paired test results for East Cape soils.

The study data was further examined to determine whether soil type or moisture content have an impact on the CBR/CIV correlation. A multivariate regression analysis was completed, showing that both 'wet' soils (as indicated in Figure 4) and lean clay soils both have a significant effect ($p < 0.05$) on the CIV/CBR correlation. A check for co-variance indicated that lean clay soils and 'wet' soils were dependent variables, such that using the 'wet' variable alone was sufficient to allow for both variables. An additional benefit of using moisture content state alone is that it is possible to determine in the field whether a soil is excessively wet by visual examination and/or feel. Determining the particle size distribution of a fine-grained soil is a significantly more complex undertaking.

The CIV and CBR paired test results are again presented as Figure 6, with the results for soils prepared in the 'wet' state excluded from the correlation. The R^2 value has further decrease due to the reduction in sample size. However, the revised correlation equation is clearly more able to predict CBR for a single data point, particularly at the lower-range CBR values where subgrade strength becomes most critical for pavement design. The reason for 'wet' soils producing a CIV/CBR correlation significantly different to 'dry' or 'optimum' soils may be attributed to the impact nature of the CIST test, where the pore water pressure in the 'wet' soil matrix resists the instantaneous impact of the drop weight, and thus gives higher CIV results. This compares to the CBR test that is less affected by pore water pressure, as this test applies a slow constant force.

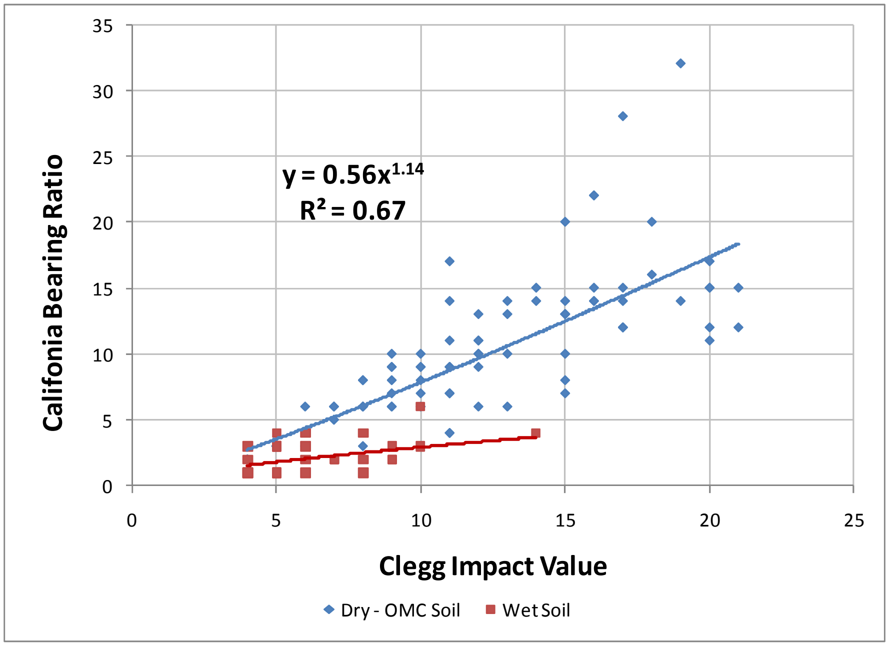

Figure 6: CIV to CBR paired test results for East Cape soils with 'wet' soils excluded from the correlation.

The resulting correlation equation developed from this study, once 'wet' soils are excluded is:

(1)

Note that this correlation is flatter than the published correlations presented in Figure 2. Consequently, for CIV>13, this correlation will tend to be conservative. For CIV<13, this correlation will predict CBR values that are similar to the Clegg (1986) and Mathur and Coghlans correlations. The R^2 value for this equation is 0.67, which indicates reasonably strong correlation for a natural system, such as soil bearing strength where there are many complicating factors because of the variable nature of soils. This may be adequate for many design decisions. Kestler (2003) states that "Although the correlation is not particularly great and is not being recommended in important situations, CIST readings can be roughly correlated to CBR". Improved accuracy may be achieved by taking and averaging multiple CIST readings.

Conclusion

The CIST is a low-cost, portable and simple-to-use tool for rapid evaluation of subgrade bearing strength. This study shows that existing correlations between CIV and CBR tend to over-predict CBR for low-strength subgrade soils. Over-estimation at the lower scale of CBR values can have significant implications on the survivability of subsequently designed forest road pavements, while under-estimation can result in over designed and excessively expensive roads.

A study of 17 subgrade soils from forested regions of the East Cape, New Zealand was conducted to calculate a region-and application-specific CIV to CBR correlation equation:

$$CBR = 0.564(CIV)^{1.144}$$

It is recommended that the CIST should not be used to test the bearing strength of 'wet' soils, as the CIST has a strong tendency to over-predict the CBR strength of soils in this condition. It is further recommended that multiple CIST readings are taken at any forest road subgrade site and averaged in order to improve CBR predictability.

Acknowledgements

The support of the East Cape offices of Ernslaw One Ltd, Hikurangi Forest Farms Ltd, and Juken NZ Ltd are acknowledged. Both research assistants, Robert McGregor and Ivan Aleksandrov, were supported by Summer Scholarships jointly funded by the University of Canterbury and the Tertiary Education Commission of New Zealand.

Literature

Al-Amoudi, O.S.B., Asi, I.M., Al-Abdul Wahhab, H.I. and Khan, Z.A. 2002. Clegg Hammer – California-Bearing Ratio Correlations. Journal of Materials in Civil Engineering. Nov/Dec. pp 512-523.

Clegg, B. 1976. An impact testing device for in situ base course evaluation. ARRB Proceedings, Volume 8.

Clegg, B. 1978. An impact Soil Test for Low Cost Roads. Presented 2nd Conference of the Road Engineering Association of Asia & Australia, Manila.

Clegg, B. 1986. Correlation with California bearing ratio. Dr Baden Clegg Pty. Ltd. Newsletter 2. 2pp

Gulen, S., and McDaniel, R.S. 1990. Use of Clegg Hammer for Compaction Control. Indiana Department of Transportation. 17pp.

Kestler, M.A. 2003. Techniques for Extending the Life of Low-Volume Roads in Seasonal Frost Areas. Transportation Research Record. 1819: 275-284.

Mathur, T. S., and Coghlans, G. T. 1987. The use of the Clegg impact tester in managing and designing aggregate-surfaced roads. Transportation Research Board, *4th Int. Conf. on Low-Volume Roads*, 1, Washington, D.C., pp 232–236.

Pidwerbesky, B. 1997. Evaluation of non-destructive in-situ tests for unbound granular pavements. IPENZ Transactions, Vol. 24, No.1

Standards New Zealand. 1986. Methods of testing soils for civil engineering purpose. Soil Testing Committee.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Changes in Wood Procurement Strategies in Virginia: Coping with Market Volatility

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ABSTRACT - Timber procurement strategies in Virginia have gone through a multitude of changes throughout the past decade. There has been a significant shift away from company owned fee lands to more privately owned timberlands. According to 29 procurement foresters from the pulp/paper/fiber, wood dealer/broker, and solid wood product sectors, fee lands encompass less than 10% of their timber acquisitions. Of the foresters surveyed, 79% noted a shift away from fee lands in the past 5 years, and 66% foresee the elimination of fee lands 5 years in the future. The majority of the foresters (72%) are responsible for supplying standing timber to less than 5 logging operations. Most (45%) noted this number to be less than 5 years ago and 55% expect the number to decrease 5 years in the future. The general consensus among the foresters was that tract sizes will decrease from an average of 40 to 80 acres at present time to 20 to 40 acres or less 5 years in the future. Similarly, they will be forced to expand their operating range in order to purchase stumpage. Foresters were also asked about their concerns over the biomass-to-energy industry in Virginia. The majority expressed a concern for an increase in procurement competition due to the new markets. However, most felt that an increase in the biomass-to-energy industry would improve their company's profitability. Currently, only 24% noted that they had changed their procurement practices due to biomass markets. The findings of this study suggest that procurement foresters in Virginia must be able to adapt to changes in timber markets and availability to remain viable.

INTRODUCTION

In the state of Virginia, 15.72 million acres of land (62% of total land) are considered forest land. Included in the 62% of forest land, 15.2 million acres are classified as commercial timberland with the remaining 500,000 acres being classified as reserved forest land. It has been found that Virginia losses approximately 27,000 acres of forest land each year. Land ownership by forest products firms has declined to less than four percent (550,000 acres) of the state's total forested area. In 2001, forest products firms owned 70% of the total forest land in Virginia and 11% in 1992 (Virginia Department of Forestry 2008). Most forest products firms are relying less on wood from company lands that is harvested by company crews and more on independent contractors (Lones and Hoffman 1990). As a result, many procurement foresters in Virginia have been forced to shift their business interest away from fee lands owned by forest products firms. The realignment of forest products industry land ownership has been found to cause concerns in other southern states that are similar to Virginia (Moldenhauer and Bolding 2009). These concerns stem from the uncertainty about future wood supplies that are affected by factors related to population pressures, such as sprawl, development, and shrinking woodlot sizes (Egan et al. 2007).

Little has been documented concerning procurement practices in Virginia. Therefore, Virginia procurement practices were studied to determine current trends in the industry and how those trends have changed in the past 5 years and how they are expected to change 5 years in the future. A survey of procurement foresters about their business habits could provide a means of understanding the profession and the ways they must adapt to an ever changing industry.

METHODS

A survey instrument was constructed in the fall of 2009 to assess changes in wood procurement strategies in Virginia based on responses from active procurement foresters. Foresters were randomly selected from three procurement sectors including: pulp/paper/fiber, wood dealer/brokers, and solid wood products. Survey participants were primarily chosen from the membership list of the Virginia Forestry Association (VFA). The initial survey population consisted of 10 foresters from each procurement sector.

Each of the 30 foresters was contacted via telephone communication. The first communication acted as a pre-notice that a survey would be sent via e-mail. The email included an online link to the actual survey. Surveys were administered and anonymously completed using survey.vt.edu which is an online survey system that is available to Virginia Tech students, faculty, and staff. At the end of the survey process, there were 29 respondents that included 9 procurement foresters from the pulp/paper/fiber sector, 10 from the wood dealer/broker sector, and 10 from the solid wood products sector. Completed surveys from responding foresters were compiled automatically by the survey.vt.edu system.

The survey consisted of 41 multiple choice and 3 short answer questions which concentrated on changes that have occurred in the procurement industry in the past 5 years and what changes are expected to occur 5 years in the future. Questions also focused on utilization of fee lands, changes in harvested tract sizes, changes in competition pressure, and concerns over the biomass-to-energy industry.

RESULTS AND DISCUSSION

Responding procurement foresters indicated that the years they began their career ranged from 1973 to 2006. Each forester was asked what county they primarily conduct business. The responses incorporated 16 counties in Virginia that included: Allegheny, Appomattox, Bedford, Botetourt, Brunswick, Carroll, Charlotte, Culpeper, Fluvanna, Greensville, King William, Lunenburg, Mecklenburg, Patrick, Spotsylvania, and Westmoreland counties. The primary product purchased was softwood pulpwood (41%), followed by hardwood sawtimber (24%), hardwood pulpwood (17%), and softwood sawtimber (17%).

Each procurement forester was asked to rate the percentage of their timber acquisitions that occurred on industry or company owned lands (fee lands) (Table 1). Seventy-seven percent of pulp/paper/fiber procurement foresters utilize fee lands in less than 10% of their timber acquisitions. Similar responses were found for wood dealers/brokers and solid wood products foresters with 90% and 50% noting that less than 10% of their acquisitions originate from fee lands, respectively. Only one survey participant responded that greater than 30% of their timber acquisitions occurred on fee lands. The majority of all foresters (79%) responded that they had noticed a shift away from fee lands in the past five years and most (66%) foresee the elimination of fee lands five years in the future (Table 2). The responses in the survey indicated that fee lands are becoming an obsolete means of supplying standing timber to procurement foresters. Therefore, they have been forced to utilize other sources such as private landowners.

Table 1: Response to the following question: What percentage of your timber acquisitions occur on industry or company owned land (fee land)?

	<10%	10-20%	20-30%	>30%
<u>Total</u>	<u>21 (72%)</u>	<u>5 (17%)</u>	<u>2 (7%)</u>	<u>1 (3%)</u>
pulp/paper/fiber	7 (77%)	1 (11%)	0	1 (11%)
wood dealer/broker	9 (90%)	1 (10%)	0	0
solid wood products	5 (50%)	3 (30%)	2 (20%)	0

Table 2: Response to the following questions: Have you noticed a shift away from fee lands in the past 5 years and do you foresee the elimination of fee lands in 5 years?

	Percent responding YES	
	shift away since 2004	elimination of fee lands by 2014
<u>Total</u>	<u>23 (79%)</u>	<u>19 (66%)</u>
pulp/paper/fiber	8 (88%)	6 (66%)
wood dealer/broker	7 (70%)	8 (80%)
solid wood products	8 (80%)	5 (50%)

Based on responses, 72% of the procurement foresters are responsible for supplying standing timber to less than five harvesting operations in order for them to maintain production. Six responses (21%) indicated that they were responsible for between five and ten harvesting operations, while only two were responsible for more than ten. Most (45%) responded that this number was less than five years ago and the majority (55%) felt that the number will continue to decrease five years in the future.

Another significant issue involved the current average tract size purchased and how it has changed from five years ago and how they expect it to change five years in the future (Table 3). Foresters were asked to verify if their tract sizes were less than 10 acres, 10 to 20 acres, 20 to 40 acres, 40 to 80 acres, or greater than 80 acres. It is apparent that the current average tract size purchased is between 40 and 80 acres according to 48% of the respondents. A large percentage (45%) responded that their current tract sizes are between 20 and 40 acres. When asked what their average tract size was five years ago, 55% responded that it was similar to current values. However, 34% noted that their average tract size was greater than 80 acres five years ago, whereas only one forester responded that their tract size was currently greater than 80 acres. Lastly, each forester was asked to predict what their average purchased tract size will be five years in the future. The survey determined that the majority (41%) of the foresters feel that tract sizes will be between 20 and 40 acres in 2014. Also, a large percentage (35%) believes that they will be purchasing tracts less than 20 acres. It was determined that the general trend has been a decrease in tract sizes in the past 5 years and will continue to decrease in the future.

Table 3: Response to the following question: What is the average tract size that your loggers harvest?

	<10 acres	10-20 acres	20-40 acres	40-80 acres	>80 acres
2004 - total	0	0	3 (10%)	16 (55%)	10 (34%)
pulp/paper/fiber	0	0	1 (12%)	4 (44%)	4 (44%)
wood dealer/broker	0	0	1 (10%)	7 (70%)	2 (20%)
solid wood products	0	0	1 (10%)	5 (50%)	4 (40%)
2009 - total	0	1 (3%)	13 (45%)	14 (48%)	1 (3%)
pulp/paper/fiber	0	0	4 (44%)	5 (56%)	0
wood dealer/broker	0	0	4 (40%)	5 (50%)	1 (10%)
solid wood products	0	1 (10%)	5 (50%)	4 (40%)	0
2014 - total	2 (7%)	8 (28%)	12 (41%)	7 (24%)	0
pulp/paper/fiber	0	3 (33%)	5 (55%)	1 (12%)	0
wood dealer/broker	1 (10%)	2 (20%)	3 (30%)	4 (40%)	0
solid wood products	1 (10%)	3 (30%)	4 (40%)	2 (20%)	0

Each procurement forester was asked which method of payment they preferred when purchasing timber. The majority (55%) responded that they prefer to purchase timber using unit sales, while 41% prefer lump sum. The remaining 4% prefer an undisclosed method. With regards to sealed bid timber sales, 72% of the foresters responded that they purchase less than 25% of the tracts that they bid on. Seventeen percent noted that they purchase between 25 and 50% of the tracts that they bid on, while 10% purchase between 50 and 75%.

In order to determine the average woodshed size for a procurement forester in Virginia, they were asked the maximum distance that they would drive to look a tract of timber. The foresters were asked to rate their maximum travel distance as less than 50 miles, 50 to 100 miles, or more than 100 miles. Only one respondent answered that they will not drive more than 50 miles. Nineteen (66%) answered that they typically will drive a maximum of 50 to 100 miles to look at a tract of timber, while 9 (31%) will drive as much as 100 miles or more. The foresters were asked if the maximum number of miles that they are driving currently is more or less than 5 years ago. The responses were nearly equally split with only 25 foresters responding to the question. Thirteen (52%) foresters responded that they are driving more miles than they were 5 years ago, while twelve (48%) felt that they were driving fewer miles. Lastly, they were asked if they thought they would be driving farther 5 years in the future. The responses indicated that 66% (19) of the foresters believe they will be driving farther, while 34% (10) do not foresee an increase in mileage for timber procurement.

Procurement foresters in Virginia must cope with competition on a daily basis. Therefore, the survey asked if the foresters had noticed an increase in competition pressure for procuring wood. The majority (93%) answered that they had noticed an increase, while only two foresters responded that there had not been an increase. When asked if they foresee competition to increase or decrease 5 years in the future, the majority (62%) responded that there would be an increase, while 21% foresee a decrease and 17% foresee competition to remain constant.

Currently, a significant issue involving wood products and procurement in Virginia is apprehension over the growing biomass-to-energy industry. Foresters were asked if they were concerned about an increase in procurement competition from this potential new industry (Table 4). Overall, 52% responded that they were concerned about an increase, whereas 41% are not disturbed, and 7% are indifferent about the issue.

Table 4: Response to the following question: Are you concerned about an increase in procurement competition from the biomass-to-energy industry?

	Yes	No	Indifferent
Total	15 (52%)	12 (41%)	2 (7%)
pulp/paper/fiber	9 (100%)	0	0
wood dealer/broker	5 (50%)	5 (50%)	0
solid wood products	1 (10%)	7 (70%)	2 (20%)

To better understand the attitude toward the biomass-to-energy industry from the perspective of a procurement forester, each sector was asked to determine if the industry would improve their company's profitability, make their company less competitive, or have no effect on their company (Table 5). Overall, 41% believe it will improve their company's profitability, whereas 38% feel it will make them less competitive, and 21% feel it will have no effect on their company. The biomass-to-energy industry seems to be a great concern to the pulp/paper/fiber foresters due to an 88% response that the industry will make their company less competitive. However, the majority of wood dealer/broker (70%) and most of the solid wood products (40%) foresters feel that the industry will improve their company's profitability. Four solid wood products (40%) and two wood dealer/broker (20%) foresters responded that there will be no effect on their company.

Table 5: Response to the following question: Which of these best describes your attitude about the biomass-to-energy industry?

	it will improve my company's profitability	it will make my company less competitive	it will have no effect on my company
Total	12 (41%)	11 (38%)	6 (21%)
pulp/paper/fiber	1 (12%)	8 (88%)	0
wood dealer/broker	7 (70%)	1 (10%)	2 (20%)
solid wood products	4 (40%)	2 (20%)	4 (40%)

Another issue related to the biomass-to-energy industry is the concern for sufficient raw material to support proposed biomass facilities. According to 21 (72%) of the surveyed procurement foresters, Virginia has enough raw material to support the facilities. However, four pulp/paper/fiber foresters (44%) and one solid wood products forester (10%) feel that there is not enough raw material. Each forester was asked to respond as to how long they feel it will take before the biomass-to-energy industry will affect the current wood supply chain by indicating less than 1 year, 1 to 5 years, or 5 to 10 years. The majority (52%) feel that the industry will affect the wood supply chain in 1 to 5 years. Twenty four percent feel it will take 5 to 10 years, while 10% feel it will be less than 1 year. Even though the majority of respondent are concerned about an increase in procurement competition from the biomass-to-energy industry and most feel that the industry will improve their company's profitability, only five pulp/paper/fiber foresters, one wood dealer/broker forester, and one solid wood products forester responded that their company had changed its wood procurement practices due to the new markets. The remaining 22 foresters (76%) have not seen any changes with their company's wood procurement practices due to biomass utilization (Table 6).

Table 6: Response to the following questions: Has your company changed its wood procurement practices due to biomass-to-energy markets?

	Yes	No
Total	7 (24%)	22 (76%)
pulp/paper/fiber	5 (56%)	4 (44%)
wood dealer/broker	1 (10%)	9 (90%)
solid wood products	1 (10%)	9 (90%)

CONCLUSION

In Virginia, timber procurement is an important industry that encompasses foresters in the pulp/paper/fiber, wood dealer/broker, and solid wood products markets. Each sector has gone through many changes and will continue to transform in the future. Foresters must be willing to cope with market volatility in order to continue to be successful. A significant change that has affected wood procurement is the shift away from company owned fee lands. This shift has caused foresters to rely on secondary sources to provide raw materials. The trend for the future tends to point to smaller operations where foresters are responsible for fewer crews on smaller tracts of land with increased competition. There also seems to be a need for willingness to expand woodsheds and operating ranges in order to find sufficient raw material to sustain production. Due to the inevitable increase in the biomass-to-energy industry, foresters must also be willing to adapt to those market changes. One thing is for certain, the procurement industry has changed as a whole in the past five years, and it will continue to change in the future. It seems that foresters understand that more changes are to come and that success depends on their ability to adapt.

LITERATURE CITED

Egan, A., D. Taggart, and I. Annis. 2007. Effects of Population Pressures on Wood Procurement and Logging Opportunities in Northern New England. Northern Journal of Applied Forestry 24(2):85-90.

Lones, J.R. and B.F. Hoffman. 1990. Wood Procurement Practices in Maine. Forest Products Journal 40(1):25-28.

Moldenhauer, M.C. and M.C. Bolding. 2009. Parcelization of South Carolina's Private Forestland: Loggers' Reaction to a Growing Threat. Forest Products Journal 59(6):37-43.

Virginia Department of Forestry. 2008. 2008 *State of the Forest: Annual Report on Virginia's Forest*.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Ideas Fuel the Future: The Changing Role of Forest Engineers and Foresters

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Abstract

Professional forest engineers and foresters have made profound contributions to society in the last century and are poised to continue; however, the employment/social contract is changing. The past relationships between workers, employers and society are reviewed and brought up to current conditions. Professionals need to reestablish their responsibility for managing their own careers by considering themselves differently than labor market units. "You are your own best asset" as a guiding principle demands professionals take action. Individually and collectively, professionals need to (1) assert their contributions are important to society (2) perform in an ethical, competent and caring fashion on important operations that are technically feasible, economically viable and environmentally sound and (3) let employers, society, supporters and detractors know that professional performance is in everyone's interest. Professionals need to work together with professional organizations, educational institutions, and the organizations that license, accredit and certify professionals to advance society's interest in managing forest lands and the necessary operations to produce goods, services and the ideas that fuel the future.

Introduction

Dam! The Employment Paradigm has shifted again and I am out of work! I've been right-sized, down-sized, out-sourced, rationalized and been made redundant. I haven't changed. The employment-social contract changed. An abridged version of the history follows:

- My forefathers were part of a tribe or clan and I worked with everyone to stay alive.
- When we farmed for landlords/overlords, we starved but were needed.
- Some worked for Masters in Guilds but apprenticeship was slavery.
- The Industrial Revolution needed workers because the kids couldn't keep up.
- Revolutions for liberty and freedom brought the right to own a farm or build a business but no guarantees of success for workers.
- First unions, then government took up worker causes but firms grew large and multi-national.
- For a time, workers were part of a huge "family" with a corporate logo and "benefits."
- Late century economic cycles led to smaller firms and contractors rather than company employees.
- At present, overall economic recession, job losses, and the deepest downturn in the forest products sector in the last 40 years all leave professionals and workers uncertain, afraid, and dismayed over their career choices.

The current economic cycles and gigantic transnational shifts result in workers, managers, owners and families at risk for how capital and labor resources will function in the next decade. Who will I work for? What will I do? How will I get paid: Vouchers?, Food Coupons?, Energy Coupons?, Health Credits?, Carbon Credits?, or Physical Assets?

Professionals historically had it better because they were recognized for their value to the employment-social contract. However, the European "Forstmeister" with attending social status (same level as community mayor) never took hold in North America. Technical knowledge of professionals was crucial in building the engine of wealth for our society and those professionals were rewarded. Once the systems approach built the wealth, the financiers, re-distributors, and regulators asserted their power to conserve and build wealth by instruments other than innovation. Engineering became an international/national commodity and forestry devolved into "terrestrial ecosystems," "natural" resources, and carbon credit accounting.

In times of changing forest land tenure, ownership of production facilities, and changing business models, what does a professional face other than career uncertainty? Who will look out for the future professionals whose recent expectations were formed in a nurturing family and educational institution structure? It won't be employers unless your father owns the firm! It won't be government!

The answer is you—yourself!

You are your own best asset. And, you are responsible for managing yourself. While family, educational organizations, and your social network helped produce your talents, you put yourself into the preparation, the studying, and the graduation and licensing. Your career as a professional carries the obligation to speak out for your own interests and the interests of future professionals.

Many are uncomfortable with the advice of self-help gurus that preach: You don't work FOR "Excel Forestry"; you work FOR YOURSELF at "Excel Forestry." Past generations felt loyal to employers and were mostly rewarded for it. However, recent heart-breaking closures, buyouts, recession sales, and budget shifts left employers/managers no choices but to do the bidding of those who had other agendas than worker morale.

Employment-Social Contract

The social contract with professionals is different from the employment arrangement. Society's recognition of your profession leaves you with demands that extend beyond your employer's interests and your own interests in personal gain. You are called to account for society's interest in its health, safety, environment, efficiency and effectiveness as you ethically perform professional tasks. Your view must include not only present circumstances but how the future will judge your decisions.

While you are not required to acknowledge those who brought the profession to where you now benefit, it is a sobering review to see how your predecessors were stewards of ethical performance. You now carry that responsibility for future professionals. They will stand on your shoulders as you have stood on those before you.

A Way Forward

How do you serve yourself, your profession, and society? First, you assert that your contributions are important to people and what they care about. Second, you perform in an ethical, competent and caring fashion on important operations that are technically feasible, economically viable and environmentally sound. Third, you let employers, society, supporters and detractors know that professional performance is in everyone's interest.

Asserting yourself comes unnaturally and pushing your profession must be somebody else's job-- right? It's not….it's yours! Think of the ways minorities have asserted their rights, protested their mistreatment, stood together to achieve a purpose, and restructured social views to recognize their demands. Guess what? You are a minority! You are one of a small group of forest engineers and forest managers who can protect, utilize, and conserve vast forest resources of the Nation. Like other minority groups, you and your professional colleagues **must** be the ones to speak out. You **must** realize no one else will do it for you. Furthermore, if professionals do not speak up, others (media, extremist groups, politicians) will fill the void with non-scientific misinformation.

You do not need to be a single voice crying in a wilderness. You have allies in your efforts to advance your profession. You can group together with others in a professional organization. The educational institutions that prepare foresters and forest engineers should support professionals in practice and recruit future professionals. Licensing and certification boards, agencies and organizations should assert their missions to protect the public interests they represent. Finally, your professional organization should seek coalitions with groups of the forestry sector to increase influence. Sometimes a group is one person in the Senate, House or other elected office. Let's examine the allies of professional foresters and forest engineers.

Professional Organizations

The Society of American Foresters (SAF) is the oldest and most diverse professional forestry organization. Founded by Conservationist/Politician Gifford Pinschot in 1900, SAF fields a national office and regional/state societies. SAF functions as a national voice for foresters, a policy reviewer, custodian of professional accreditation, and even a career center. Annual and state society meetings bring foresters together and scientific and popular publications enhance communications. The SAF supports credentialing with certification, registration, and licensing of foresters with fifteen states having jurisdictional responsibilities. Many such states recognize the combination of an SAF accredited degree plus specified experience for certification or registration. Licensing requires approved graduation, experience, and examinations. SAF operates its own certification program because of the variability of state certification programs. Certified Foresters™ (CF) meet examination, experience, and continuing education requirements. CF must also meet codes of practice, the SAF ethical practices, and are subject to complaints and decertification by SAF.

It appears that state/regional SAF societies have considerable latitude to advance the forestry profession in their areas of influence. While actions may be taken to punish or expel an SAF member with substantiated complaints for violating the code of ethics, efforts to insist on employing professional foresters for management in state, federal, or private forestry are noticeably missing. A position statement of SAF studiously avoids using professional foresters in favor of "natural resource" managers. Some agencies employ quasi-certification programs for specialties in the agencies for hydrologists, fisheries, etc. but those same agencies may not insist on professional forestry managers.

The pattern of SAF membership is of interest. In the last century, SAF membership peaked at over 22,000 professionals--mainly graduates of forest management programs who met SAF accreditation. Membership came from federal forestry agencies, state forestry agencies, corporations, family firms, consultants, forest landowners, and academics. Current membership at 14,000 reflects a broadened definition of who is eligible besides those from accredited SAF programs. Those simply working in forestry are eligible if they are:

> … a scientist or practitioner who holds a bachelor's or higher degree within the "broad field of forestry,"* based on a curriculum that is neither SAF-accredited nor a candidate for accreditation, and who has three or more years of "qualifying experience"** within the "broad field of forestry."* Professional Members may hold any office and vote on any questions before the Society (www.safnet.org accessed on December 11, 2009)

Still, SAF faced large declines from federal, state, and corporate employees for many reasons. The agencies often did not support forestry organizations when agency land management broadened to biology, wildlife, fisheries and the "whole ecosystem." Private sector losses were due to reduced forestry workforces and even some specific conflicts with SAF direction, positions, eg, landscape management, clear cutting, use of chemicals, etc.

Academics in SAF declined for a more profound reason—the shift in forestry education. At least 62 forestry schools once had SAF accredited programs. Now 43 or so are on the undergraduate accreditation track and some major forestry states like Washington have no accredited undergraduate programs in the near term. More losses will continue as higher education shifts to generic "natural resources" programs, even though SAF continues to broaden the criteria. Perhaps SAF thinks it will increase future membership by accrediting "terrestrial ecosystem" programs. Don't bet on it. In the number one Forestry College in the US, only about 20 of more than 100 active faculty are in the local SAF chapter. A similar number of retirees or emeritus faculty are still engaged with SAF but not active in education. Many of the rest of the faculty wouldn't be caught dead at an SAF function let alone be seen with their antagonists.

An optimist might think SAF would strongly advocate for the profession but national history speaks otherwise. Local SAF units might take up the cause with individual local leaders. Consulting foresters (a subgroup) have more effective voice in their National and State Association of Consulting Foresters. SAF's age distribution is another full story to be told. A recent SAF Chapter meeting had 80% or more of the attendees at retirement age or near that stage.

Forest Engineers have even less representation than foresters. The Council on Forest Engineering, founded in 1978, was set up to provide a professional forum but does not serve an advocacy role:

> The main objectives of COFE are to foster the development of forest engineering in industry, government, and in university teaching, research, and extension programs to promote the best methods of managing and operating forests; to serve the forestry profession on matters of policy in the area of forest engineering; and to disseminate

technical information on forest engineering subjects. www.cofe.org accessed on December 11, 2009

COFE's individual members and officers may speak out but they are not representative of any national or regional COFE membership. There is no mechanism for adopting policy positions. COFE provides many important functions but its not-for-profit status imposes limits to its advocacy role. The low dues structure of COFE allows its members to support an additional organization.

The Forest Engineering Professionals Association (FEPA) was formed in 2000 in the midst of a licensing controversy where the Oregon Board of Examiners for Engineering and Land Surveying (OSBEELS) refused to allow Oregon State University graduates in forest engineering to take the Fundamentals of Engineering licensing exam. OSU forest engineering graduates were eligible to take the exam since the founding of OSBEELS but a more recent rule change allowed only graduates of curricula accredited by ABET, inc., the accreditor for college and university programs in applied science, computing, engineering, and technology, to take the exam. FEPA and other industry supporters had major conflicts with OSBEELS, especially its Chairman, resulting in an Oregon State Senate bill to overturn the OSBEELS' rule and restore OSU graduates ability to take the Fundamentals exam. The FEPA Executive was charged with ethical violations by the OSBEELS Chair. Charges were dismissed and ultimately the OSBEELS Chair was removed from the Board. OSU Forest Engineering later became ABET accredited and will need to remain so under current OSBEELS regulations. FEPA's activity lessened after the conflict resolved except to advocate for forest engineering with other state Boards of licensing. FEPA is not restricted from lobbying as a "for profit" unit as are "non-profits." FEPA is now reorganizing to take up current challenges to the forest engineering profession.

The University Programs for Professional Foresters and Forest Engineers

The traditional roles of the university, particularly the land-grant institutions, had fairly well-defined missions into the 1980's which included:

- Preparation of workforces, especially those in professional fields like engineering, law, medicine, and of course, forestry. Employers and alumni had strong roles in curriculum content and accreditation organizations were sensitive to practicing professionals.
- Creating new knowledge—research, especially research related to needs of agriculture and basic industries fueling the local and state economies.
- Extension and Outreach: Efforts to bring the university resources to the people with
    - Problem-solving education
    - Research implementation and applied research
    - Technology transfer from the university and other sources addressed to state constituents
    - Continuing education
    - Public education
- Service: Use of faculty resources to serve on boards, commissions, and in public service roles as well as consulting that did not conflict with university functions.

The need for continuing education (CE) for practicing professionals has been recognized as a "profit center" for universities because public funding has usually not been used for CE. In regulations governing the engineering profession, continuing education is mandated and records must be kept by licensees. The Certified Forester program of the SAF requires CE for maintaining their Certification. Figure 1 shows how technological obsolescence develops over time from the graduation event. Even more significantly, the "half-life" of professionals has been recognized early on in forestry. The half-life is a measure of the decay and loss of information by professionals after graduation and during their career. For example, the half-life of foresters was estimated in 1970 at 8 years-meaning that half of the information and skills were no longer useful after that time limit. As new information is generated in a field, the half-life decreases. For engineering, the typical half-life is around 5 years and as short as 2 years with computer engineers. Half-life for professionals shortens as new information is generated as well producing a knowledge gap. There are circumstances when the half-life of new graduates is shorter than earlier graduates if the current curriculum does not meet the needs of the profession: all that is new is not good; all that is old is not bad.

The modern U.S. university has adopted shifting roles and emerging new roles as it responds to perceived needs of society and what universities think society will support. Consider that:

- Land grant administrators pontificate that they are "state-assisted" universities not state supported ones.
- Undergraduate education is subsidized by other university functions of research, extension/outreach, or service.
- Tight state budgets produce downsizing and consolidation in programs that produce professionals that serve society
- The university is on a pay as you go basis for research, continuing education and extension/outreach programs to clients will pay for service directly
- Federal agencies have shifted to "Big Science" and big (headed) scientists where grants less than $100k to universities are nuisance grants because they don't generate sufficient "overhead", "indirect costs", infrastructure support or administrator salaries. The multi-million, multi-year unrestricted grant is the measure of success.
- Rush to change the names and missions of forestry institutions to what faculty think will attract hordes of students.
- Professional faculty would rather assign a grad student to "jazz up" the website rather than use their time to recruit students, provide CE to professionals, or actually recruit students.

There is little benefit in lamenting a past that will not return. However, professionals and even faculty in professional academic units may not be well served by a future the trends above suggest. There would be mega-units in universities that feature "Natural Resources" and "Terrestrial Ecosystems" as themes within large institutes where student quantity not quality is the goal and the end result. Faculty are already set up in tiers where faculty "super stars" garnering large research grants are favored while faculty who meet student, alumni, and society needs are second tier in promotion, salary and hiring. There is already a gulf between faculty super stars and the practicing professionals that will result in professionals seeking their fundamental education elsewhere and organizing among themselves the continuing education needed. What could make the future work between professionals and the university?

A positive future can be seen when university faculty who are not on a federal agency funding short list realize they cannot survive without constituents and begin to seek cooperative efforts with professionals,. Cooperative education where students spend part of their university time in a firm (for pay) can result in closer ties to professionals. Professionals will need to be teachers and mentors and CO-OP students will challenge professors lacking "real world" credentials. Cooperative research will help professors address real problems rather than planning paradigms and global models. The forestry sector can better understand the value of information and what it takes to make good decisions. Forestry professionals may be willing to pay for CE but need to help universities offer what will benefit them.

Forestry professionals may not realize the power they have as constituents of the university. State legislators take pride in supporting "their" universities and respond to their constituents who engage their support in making the "state assistance" provided to universities actually meet some needs. Also, university administrators respond to outside influence in greater measure than to internal faculty who they disregard at times as being self serving. Forestry professionals need to know the leverage points within the universities and use them or lose them. When universities fail to respond to professionals' needs, it is necessary to close the door on university cooperation by slamming it loudly and seeking those who will meet the profession's needs. The door remains open!

<u>Licensing Agencies, Accreditation/Certification Boards and Employers</u>

The organizations established to assure that qualified professionals perform tasks society trusts to protect them have not been assertive in their watchdog roles. Licensing boards for forestry and engineering have generally low number of cases prosecuted. In fact, when a state forestry agency advertises for someone to lay out roads where the public (that includes contractor workers) travels and only requires a "Natural Resources" degree, the licensing agency for engineers should call out the agency. A degree in "Natural Resources" does not provide the skills to layout, design and supervise construction of public roads. Yet, the practice continues.

A typical state forestry registration organization pursues relatively few enforcement actions-- on the order of five in a ten year period. Legal conformance is mostly through information and rarely when a complaint occurs.

> It is the mission of the Board of Registration for Foresters to benefit and protect the general public and the forest resources of the State of Mississippi by regulating the practice of forestry and requiring that persons practicing or offering to practice forestry be lawfully registered to do so. The Board will promote the highest standards of professional conduct among the Registered Foresters of the State of Mississippi through Mississippi Law and the Code of Ethics for Foresters.
> http://www.cfr.msstate.edu/borf/mission.asp accessed on April 29,2010.

When catastrophes occur, eg, Katrina, the task of monitoring who does forestry can get lost in the emergency rehabilitation (Kathy Parker, personal conversation, April 29, 2010).

Employers of foresters and forest engineers as corporations, agencies and firms have not strongly supported the professional requirements. What good is a professional degree in forestry when a "natural resources" degree is all that's called for in job announcements? Agencies set low qualifications for employment to do forestry work; corporations seem to value diversity over forestry and forest engineering qualifications; and some firms describe professional job requirements and then set the educational requirement level at the technician level (2 years education) or unspecified “qualifying experience.” What do employers need to manage forest lands and what do they recruit for and promote toward? What can employers do when they find employees unable to do the tasks they were hired to perform? One western land management agency will not admit graduates of the state forestry institution to the professional forestry salary schedule because the new hires cannot perform the work needed. When these new hires complete agency education on “silviculture, surveying, roads, harvest practices, and tree identification,” they will move to the professional series. Graduates from forestry programs that meet the agency needs, start on the professional salary schedule.

What many forestry and forest engineering professionals seem not to recognize is that they are in control of the licensing/certification process and the employment demands. It is the professionals that are serving on the state Boards and it is the professionals telling the human resources folks what they want in new hires. It may be the iron law of academic loyalty that managers prefer to hire folks from their own institutions and the way they were educated. With more forest managers not trained as professional foresters or forest engineers, the demand for professionals continue to fall. When the social contract for professionals calls for high levels of training and performance, but the social employment circumstances are not reciprocal, then professionals must act to change those circumstances.

One area where professional qualifications make a large difference is in the litigation involving forest operations. Courts take a different perspective on what constitutes competency than academic recruiters or agencies whose professionals cannot qualify as experts in areas they manage. When litigation potentials are considered, the employment of professionals can be a small relative cost for most organizations.

Trajectories of Development

Accepting responsibility for the future is a paradigm shift for many individuals and professional organizations. One response to the circumstances above is for individuals and professional organizations to realize they are on a trajectory of development and that they are in control of how the trajectory unfolds. Figure 2 shows hypothetical trajectories for three types of workers over their working time. For example, the trajectory of worker A represents someone perhaps started working early and encountered a career ending event, eg, severe injury, substance abuse, or just a shortened work life. Trajectory B is typical of workers in developed countries that pass through a period of increasing income (or some measure of potential) that tails off with age. The ideal for professionals is trajectory C as a high performance worker investing in themselves and increasing and maintaining their potential. The measure of the trajectory can be whatever makes sense and income is a readily available measure. Once measured, the individual can take action to direct their trajectory as they see fit and see results. Powerful results can be seen when goals are aligned with a measure of success.

For a profession, the accumulation of individual trajectories forms the group trajectory. However, the measurement over time might be something different than median salary by year. Professional organizations may want to chart enrollment in professional programs, graduates by curriculum, organization membership, or what makes sense as a target to monitor. Like individuals, professionals can take collective action to make improvements with corresponding results seen in their trajectory.

One immediate step for individual professionals involves how they speak about their job to everyone around them. The "baby boomers" put forest rangers on high pedestals along with firemen and doctors. They came in contact with forest rangers on camping trips and recreation activities and understood foresters were the ones looking after the forest. That image was hi-jacked by environmental groups who linked "foresters" with the destruction they claimed was being done to the forest by loggers and characters from "Fern Gully." Professionals doing forestry work responded by calling themselves biologists, hydrologists, ecologists, and any "ology" rather than being called a forester. Forestry professionals need to speak with friends, neighbors and anyone who will listen about what their job as a forester or forest engineer entails, eg, planting trees, making and fixing roads in the forest, putting out fires, and harvesting trees so young trees can grow. The people around us need to understand that the forester who they know as a really good person, helping out with community events, volunteering to help others, and so forth is the same person taking care of the forest. Don't apologize for your job; explain your job! More collective actions will be needed by the forestry profession but like an individual rock thrown in a lake, the individual forester's action causes ripples of awareness to spread widely in their communities.

The future demands new, novel thinking from professionals to fuel the forestry sector. The direct challenge for individuals and professional organizations is simply:

ACT ! AND ACT NOW TO CONTROL YOUR FUTURE!

Sources:

Green, Carol C. 2006.Forestry Education in the United States. Issues in Science and Technology Librarianship, http://www.library.ucsb.edu/istl/46-supp/article7.html accessed on 4-30-2010

Kruchten, Philippe. 2008. "The Biological Half-Life of Software Engineering Ideas," *IEEE Software*, vol. 25, no. 5, pp. 10-11, Sep./Oct. 2008, doi:10.1109/MS.2008.127

Kathy Parker, personal conversation, April 29, 2010. Mississippi Board of Registration for Foresters, Mississippi State University, MS 601-325-2772

Stoltenberg, Carl & Dils, Robert E. 1972. Updating professional skills to meet changing forestry needs. Seventh World Forestry Congress. Food and Agriculture Org. of United Nations. Buenos Aires. Unasylva. Vol 25. No 104.

Wulf, Wm. A, 1998. The Urgency of Engineering Education Reform
The Bridge, National Academy of Engineering of the National Academies. Volume: 28, Number: 1 - Mar 1998

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Figure 1. How technological obsolescence develops over time

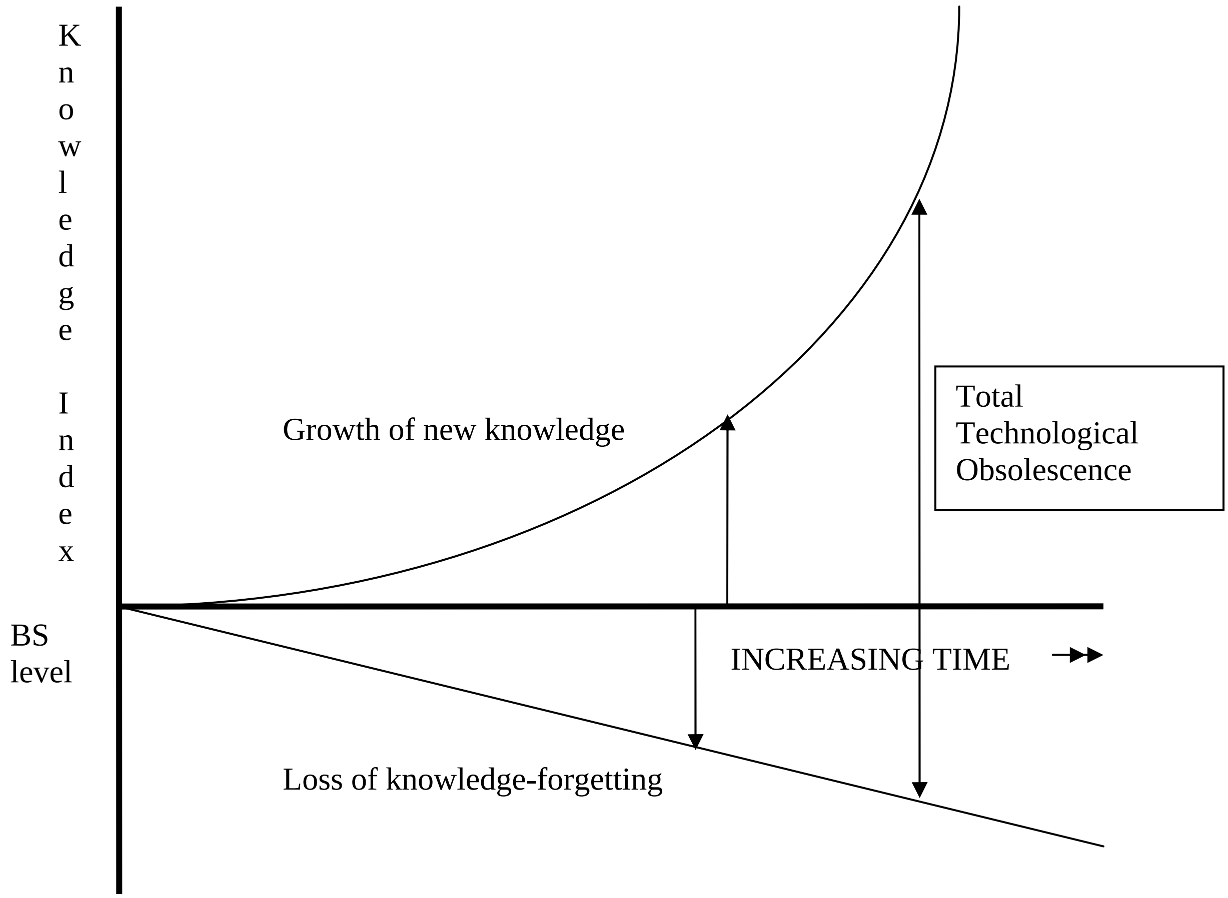
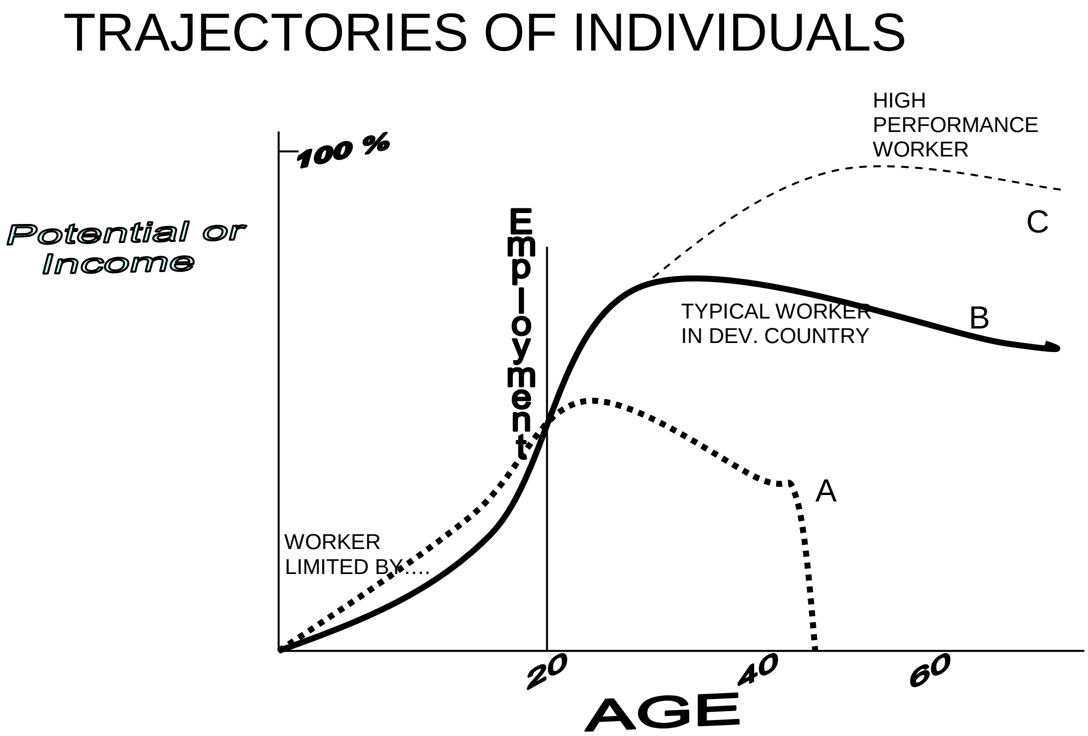


Figure 2. Trajectories of Development



FPSuite: An Integrated Process Control Platform for Forestry Operations

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Increasingly, the forest industry must be able to adjust quickly to new market conditions with a very flexible supply chain. In recent years, FPInnovations has developed various precision forestry tools for this purpose. *FPSuite* is a set of software and electronic modules forming an integrated process control platform for forestry operations:

- *FPInterface*, a GIS-based software tool, is used to simulate and plan operations. Working directly with forest maps, it contains modules to simulate and predict harvesting, transportation, road, silviculture and biomass supply costs. It can also be used to plan for customer (mill) demands, and prepare operational calendars.
- *FPDat* collects operational data in forest equipment. A successor to the highly-successful *MultiDAT*, the *FPDat* can collect data on machine utilization, track machine displacement using GPS, and acquire data from the machine through electrical channels and links to the electronic engine.
- *FPCom* is the communication link of *FPSuite*. *FPCom Satellite* is a modem used to transfer data between the field and the office based on the Iridium satellite network. *FPCom Mobile* uses short-range modems to collect data from machines to a computer installed in a light vehicle. This computer acts as the data carrier and cellular link is used to move data to or from the computer and the office.
- *FPTrak* is the integrated performance management and production reporting module of *FPSuite*. It provides the user with production summaries and key performance indicators. The reporting information can be accessed through a web platform by both operations managers and forest contractors. *FPTrak* can loop back actual performance into *FPInterface*'s planning module to enable re-adjustments to the planning or the schedules.

The four *FPSuite* modules can be used independently, in conjunction with other data streams or all together in an inclusive process control platform. FPInnovations is currently in the final phases of development and early stages of implementation of *FPSuite* on Canadian forest operations.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Designing for effective evaluations of soil erosion and storm runoff

J. McFero Grace III, Mark Dougherty, Emily Carter, and Ali Baharanyi

Soil erosion and water quality concerns surrounding sediment movement related to forest management strategies and disturbances continues to be a focus in forest management. However, there is limited information documenting the effectiveness of prescribed practices in reducing sediment loads from source activities, specifically for forest road systems. This is primarily due to the complexity of assessing the effectiveness of erosion control, stormwater management, and BMPs on the forest landscape. Monitoring designs for effective evaluations of erosion and sediment control practices are critical to quantify reductions in sediment contributed from forest operations. To explore this topic related to effective monitoring designs, this paper presents two forest road erosion monitoring designs to evaluate erosion control treatments in central and south Alabama. One design consists of sharp crested weirs and rectangular approaches in combination with runoff tipping buckets and stormwater samplers to evaluate runoff from forest road sections. Another design uses bound plots in conjunction with Coshocton wheels to quantify storm runoff from erosion plots on road sideslopes. This paper details general engineering design aspects involved in evaluating soil erosion and storm runoff. A point of emphasis in this work is balancing several trade-offs encountered in soil erosion and stormwater research related to monitoring and evaluating soil erosion in forested environment. This work explores the influence of site hydrology and "right sizing" monitoring equipment based on site conditions, study objectives, and reporting requirements. In addition, the paper presents concepts involved with utilizing erosion models as tools to assist in effective stormwater monitoring designs. An underlying objective in this presentation is to explore considerations regarding the selection of monitoring equipment and structures based on monitoring constraints, design storms, and economics.

KEYWORDS: Design, Soil Erosion, Stormwater, Sediment Control, Modeling, Hydrology

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

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Paper Title:
Estimating Construction and Closure Costs of Minimum Standard Forest Roads, Bladed Skid Trails, and Water Crossings

ABSTRACT - Forest road construction, maintenance, and/or closure are necessary for timber harvests but can add significant costs to the operation. Additionally, forest land managers often have difficulties estimating these costs. Their cost estimations are generally based upon previous personal experience, machine rate estimations, or acquisition of contractor bids. While these techniques can produce adequate results, they often require more experience or data requirements than some managers have available. In these situations a simplified model for estimating costs would be useful. The Virginia Tech Forest Road Cost (VTFRC) model was developed to estimate the costs of minimum standard haul roads, bladed skid trails, as well as bridges and other water crossings. Previous models have been based on many different actual construction costs as well as cost surveys. While this model is similar to previous ones, it has been updated to reflect current prices as well as the costs associated with bladed skid trails that are often used in steep, mountainous terrain. Previous models were used successfully by approximately 80% of sampled foresters to successfully estimate costs to within +/- 10% of actual construction costs in the Coastal Plain, Piedmont, and Southern Appalachian Mountains.

Introduction

Forest roads can be the most costly aspect of forest operations both monetarily and environmentally (Walbridge 1997, Swift et al. 1999). The environmental impacts of roads have received the majority of the public's attention, and as a result states have included recommendations for roads in their Best Management Practices (BMPs) for protection of water and site quality (Aust and Blinn 2004). The costs of building forest roads are less of a concern to the public, but they can be the difference between profit and loss in many timber acquisitions. Despite this, many foresters struggle to accurately estimate road construction costs due to variability (Groves et al. 1979, Kochendefer et al. 1984, Jackson and Loveless 1986) and a lack of published information that actually quantifies costs associated with various road construction activities (Aust and Shaffer 2001, Aust et al. 2001 and 2003).

There have, however, been several models developed that estimate construction costs for forest roads. Kochenderfer et al. (1984) provided actual construction costs of minimum standard haul roads in the central Appalachians, but this information cannot be easily applied to other regions. The TRACER model (Akay and Sessions 2005) uses road design estimates and selected road standards to compare alternate road locations. This model requires input characteristics of high standard roads, and this entails significant reconnaissance which is not practical for minimum standard forest roads. The USDA Forest Service (2009) developed a manual for estimating road costs that provides detailed cost information as well as road building contacts. This manual is most applicable to the western United States and requires more expertise and data collection than is practical for minimum standard forest roads.

Typically, foresters estimate road costs using the machine rate, personal experience, actual contractor bids, or spreadsheets (Aust et al. 2005). The machine rate method assumes that one knows the cost per unit time of operating machinery and does not take all road building costs into account. This method also requires a moderate level of expertise. Personal experience works for foresters who have been in a region for a long period of time and have developed "rules of thumb" for road building costs. This method may not be effective if the forester moves to a new region or is at the beginning of his/her career. Actual contractor bids result in extremely accurate cost estimates, but these require considerable lead time and work best when designed road plans and profiles exist. Spreadsheets can provide general estimates of road construction cost, but they should not be relied on to provide exact values.

AVLO is a spreadsheet style approach that itemizes major costs for the common activities of road maintenance, upgrade, and construction. The overall goal of this spreadsheet was to provide an estimation technique that was simple and field expedient that could be used to train new foresters to consider the major road components and costs, provide foresters with a road cost technique that can be simply modified to reflect costs in a particular area, and to provide a generalized technique for modifying timber values to adequately reflect road costs (O'Neal et al. 2006). This model was developed several years ago and no longer accurately reflects the costs associated with forest road construction. Additionally, it did not account for costs associated with the construction of bladed skid trails which are common where slopes exceed 40% (Virginia Department of Forestry 2002). Our goal was to update costs associated with construction, maintenance, and closure of minimum standard forest roads and bladed skid trails. The new model is named the Virginia Tech Forest Road Cost Model (VTFRCM).

Methods

Costs used to develop the AVLO spreadsheet were based on those reported for road construction and maintenance, stream crossing installations, and from surveys of costs encountered by loggers (O'Neal et al. 2006). The estimates provided in our model represent a range of costs which were derived from the literature as well as consultations with stone quarries, construction and excavation companies, and personnel knowledgeable of forest road layout and construction costs in the US South (Table 1). The range of costs also reflects differences in material costs throughout the region. There is also a "default" cost provided for each component that represents an approximate average cost for all regions.

To construct our model, we attempted to include cost items for all aspects of forest road and bladed skid trail construction. To do this we relied heavily upon personal communications with loggers who commonly use bladed skid trails and construction companies that specialized in road construction. A recent survey of Virginia loggers (McKee et al. 2010) was also relied upon heavily for the costs of implementing water control structures and stream crossings. For stringer bridges and low water crossings, we used prices reported by Aust et al. (2003).

Discussion

VTFRCM is an Excel based costing system (Table 2) adapted from the itemized planning guide developed by Aust et al. (2005) and O'Neal et al. (2006). Excel is not required, the user can enter the categories into whatever format is desired, or simply carry a printed copy of the spreadsheet to the field. The user steps through a series of questions identifying the road construction, repair, or maintenance activities that are appropriate for the road under consideration. Average costs are provided when the cost of an activity is unknown, and for activities where a quantity or lengths are applicable, spaces are provided for these numbers. Based on the costs of each activity, a total cost is calculated, which provides a total cost for the road construction, repair, or closure activity. There is also a section available which contains conversion tables (meters to feet, miles to feet, etc.) and a gravel weight calculator. This allows the user to input the dimension of the road and the weight of the gravel being used in lbs/ft^3 and provides the tons of gravel required.

The major differences between AVLO and VTFRCM are updated cost estimations and the addition of bladed skid trail costs. The cost components of skid trails were similar to those in road construction. However, there were fewer cost components associated with their construction (three compared to nine in road construction). We assumed gravel would not be used as part of a skid trail, and clearing and grubbing, cut and fill slopes, and shaping final surface grades were combined into one category. Other additions included Geotextile and Geoweb to water control structures as well as costs for cut and fill based on percent side slope. Closure costs were also expanded to include mulch and slash application, seed and fertilizer, and hydroseeding.

The differences in costs were most readily seen between the two models for portable skidder bridges, gravel, and the costs associated with equipment use. The new model was expanded to include wooden skidder bridges and the overall prices reported increased from a range of $2,000-$10,000 to a range of $1,500-$16,000. Gravel costs increased from a range of $5-$30 per ton to a range of $10-$40 per ton. The major costs associated with equipment use that increased were clearing and grubbing, cut and fill slopes, ditch construction, and shaping final surface grade.

Similarly to past spreadsheets, the most beneficial aspect of VTFRCM is that it itemizes the majority of costs associated with road construction through a step-by-step method. This ensures that all activities involved in road construction, repair, and maintenance are taken into account. Although this model has yet to be fully validated, it has been used in classroom demonstrations on road construction costs. Students were asked to estimate the cost of the road given its standards, length, and water control structures simply by using their experience in the classroom. They were then given a copy of the spreadsheet and asked to complete the same task with the VTFRCM and the given information. Their estimates using the model were within 15% of the actual cost of the road. The model requires foresters and forestry students to recognize the numerous costs associated with road building. It does not, however, calculate the exact costs since they may vary dramatically from region to region.

Table 1: Road cost estimates and source of information

Road Cost Item	Cost estimate	Source
Ford	$100-$1,500 per ford	McKee et al. 2010
Improved ford	$1,500-$2,500 per ford	Virginia Department of Forestry, Personal Communication, February 21, 2010
Culvert	$400-$2,000 per culvert	McKee et al. 2010; construction companies in the piedmont of Virginia, personal communication, February 2010
Culvert installation	$200-$600	McKee et al. 2010
Portable skidder bridges (wooden)	$1,500-$4,000 per bridge	McKee et al. 2010; construction companies in the piedmont of Virginia, personal communication, February 2010
Portable skidder bridges (steel)	$8,000-$16,000 per bridge	McKee et al. 2010; construction companies in the piedmont of Virginia, personal communication, February 2010
Stringer bridge (material and installation)	$5,000-$40,000 per bridge	Aust et al. 2003
Low water crossing	$10,000-$50,000 per crossing	Aust et al. 2003
Broad-based dips	$20-$50 per dip	Clay Sawyers, personal communication, Forest Research Manager, Reynolds Homestead, February 16, 2010
Water turnouts	$10-$25 per turnout	Shaffer et al. 1998
Geotextile	$100-$200 per 100 feet	Virginia Department of Forestry, personal communication, February 21, 2010
Geoweb	$200-$400 per panel	Virginia Department of Forestry, personal communication, February 21, 2010
Water bars	$15-$30 per water bar	Clay Sawyers, personal communication, Forest Research Manager, Reynolds Homestead, February 16, 2010
Location and gradeline installation	$500-$3,000 per mile	USDA Forest Service 2009, Aust and Shaffer 2001
Clearing and grubbing	$5,000-$10,000 per mile	USDA Forest Service 2009, Aust and Shaffer 2001
Seeding and fertilizer	$300-$500 per mile	Aust and Shaffer 2001

Table 2: VTFRCM example spreadsheet

1. What is the current road situation?

An adequate road exists-----------------------------------Stop
No road exists--Proceed to part 2
Road exists, but needs upgrade/repair----------------Proceed to part 5
Skid trail construction costs-------------------------------Proceed to part 6
Min. standard haul road and skid trail closure costs---Proceed to part 7

2. Plan for a new road (or section of road). Locate the desired road on topomap and attach map.

Estimated length of road
Traffic (comment on weight, quantity, and configuration)
Width of Road
Maximum desired grade of road
Permanent or temporary
Rock type and hardness expected (soil survey)

3. Perennial stream crossing requirements.

How many of the following are needed?

Type	Length/Quantity	Cost range per crossing	Est. cost	Total
1. Ford	0	$100-1,500/ford	500	0
2. Reinforced Ford (with geotextile and/or geoweb)	0	$1,500-2,500/ford	2000	0
3. Culvert (cost of material)	0	$400-1,500/culvert	700	0
4. Portable skidder bridges (wood)	0	$1,500-4,000/ bridge	2500	0
5. Portable skidder bridges (steel)	0	$8,000-16,000/bridge	15000	0
6. Stringer bridges (material & installation)	0	$5,000-40,000/bridge	15000	0
7. Low water crossings	0	$10,000-50,000/crossing	20000	0
8. Other options				
4. Construction costs for minimum standard haul roads.				
1. Easement Costs	0		0	0
2. Location and Gradeline Installation	0	$500-3,000/mile	500	0
3. Clearing and Grubbing	0	$5,000-10,000/mile	5000	0
4. Cut and Fill Slopes:				
1. <40% slopes	0	$700-1,500/mile	0	0
2. 40-60% slopes	0	$1,500-2,200/mile	0	0
3. >60%+ slopes	0	$2,200-4,000/mile	0	0
5. Ditch Construction	0	$1,500-3,000/mile	2000	0
6. Shaping Final Surface Grade	0	$1,000-3,000/mile	1500	0
7. Water Control:				
1. Broad Based Dips	0	$25-50/dip	30	0
2. Water Turnouts	0	$10-25/turnout	15	0
3. Culvert Installation Costs	4	$200-600/culvert	450	1800
4. Geotextile	12	$100-200/100 feet	120	1440
5. Geoweb	0	$200-400/20 foot panel	250	0
8. Seed and Fertilizer	0	$300-500/mile	400	0
9. Tons of Gravel	0	$10-40/ton	13	0
5. Improvement/Maintenance of minimum standard haul roads.				
1. Ditch Improvement/Repair	0	$750-1,500/mile	750	0
2. Re-Grading Haul Road	0	$500-1,500/mile	750	0
3. Water Control Improvements:				
1. Broad Based Dips	0	$25-50/dip	30	0
2. Water Turnouts	0	$10-25/turnout	15	0
3. Culvert Installation Costs	0	$200-600/culvert	450	0
4. Geotextile	0	$100-200/100 feet	120	0
5. Geoweb	0	$200-400/20 foot panel	250	0
4. Seed and Fertilizer	0	$300-500/mile	400	0
5. Tons of Gravel	0	$10-40/ton	20	0
6. Skid Trail Construction Costs.				
1. Gradeline Installation	0	$100-500/mile	200	0
2. Construction (machine costs)	0	$500-2,000/mile	1000	0
3. Water Crossings:				
1. Culvert installation cost	0	$200-600/culvert	450	0
2. Skidder bridge installation	0	$25-100/bridge	50	0
3. Pole bridge installation	0	$50-200/bridge	100	0
7. Minimum standard haul road and skid trail closure costs.				
1. Mulch	0	$20-50/1000 ft^2	25	0
2. Slash	0	$15-50/1000 ft^2	25	0
3. Seed and Fertilizer	0	$300-500/mile	400	0
4. Water Bars	0	$15-30/water bar	20	0
5. Disc and Seed	0	$400-800/mile	550	0
6. Gates	0	$300-1,500/gate	400	0
7. Hydroseed	0	$0.03-0.08/square foot	0.045	0
8. Other	0		0	0
8. Total Estimated Costs				3240

Literature Cited

Akay, A.E. and J. Sessions. 2005. Applying the decision support system, TRACER, to Forest Road Designs. *Western J. of Appl. For,*.20(3):184-191

Aust, W.M., and R.M. Shaffer. 2001. Costs of planning, locating, and constructing a minimum-standard forest road to meet BMP guidelines in the Appalachian mountains of Virginia. P. 1-4 24th Annual Council on Forest Engineering meeting, Snowshoe, WV, July 15-19, 2001.

Aust, W.M. and C.R. Blinn. 2004. Forestry best management practices for timber harvesting and site preparation in the eastern United States: An overview of water quality and productivity research during the past 20 years (1982-2002). *Water, Air, and Soil Pollution: Focus* 4(1): 5-36.

Aust, W.M., R.M. Visser, and W.A. Lakel III. 2005. Estimation of road costs using an itemized planning guide. FRA Technical Release: 05-R-23.

Aust, W.M., J.M.R. Visser, T.V. Gallagher, and M. Poirot. 2001. Forest road stream crossings and costs. P. 71-75 24th Annual Council on Forest Engineering meeting, Snowshoe, WV, July 15-19, 2001.

Aust, W.M., R.M. Visser, T. Gallagher, and T. Roberts. 2003. Cost of six different stream crossing options in the Appalachian area. *South J. Appl. For.* 27(1): 2003, 66-70.

Groves, F.D., R.K. Baughman, M.E. Hundley, and R.L. Sherman. 1979. Timber haul road construction in the southern mountains. *South J. Appl. For.* 3(3): 68-76.

Jackson, D.H. and R. Loveless. 1986. Predicting forest road and bridge construction costs. *West. J. Appl. For.* 1(3): 76-79.

Kochenderfer, J.N., G.W. Wendel, G.W. Smith, and H. Clay. 1984. *Cost of and soil loss on "minimum standard" forest truck roads constructed in the central Appalachians*. Res. Pap NE-544. USDA Forest Service, Northeastern Forest Experiment Station. 8 p.

McKee, S.E., L. Shenk, M.C. Bolding, and W.M. Aust. 2010. Methods and costs of skidder and truck stream crossings in Virginia. 33rd Annual Council on Forest Engineering meeting, Auburn, AL, July 6-9, 2010.

O'Neal, B.S., W.A. Lakel III, W.M. Aust, R.M. Visser. 2006. AVLO: a simplified cost analysis approach for estimating construction costs of forest roads. 29th Annual Council on Forest Engineering meeting, Coeur d'Alene, ID.

Shaffer, R.M., H.L. Haney Jr., E.G. Worrell, and W.M. Aust. 1998. Forestry BMP implementation costs for Virginia. *For. Prod. J.* 48(9): 27-29.

Swift, L.W., and R.G. Burnes. 1999. The three R's of roads: redesign, reconstruct, and restoration. *J. For.* 97(8): 40-44.

USDA Forest Service. 2009. *Cost estimating guide for road construction*. USDA Forest Service Intermountain, Southwestern Mountain Regions. 155p.

Virginia Department of Forestry. 2002. *Best management practices for water quality*. Fourth Edition. 216 p.

Walbridge, Jr., T.A. 1997. The Location of Forest Roads. Virginia Polytechnic Institute and State University, Blacksburg, VA.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Potential Improvements to Equipment and Processes
for Harvesting Forest Biomass for Energy

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2010 Council on Forest Engineering Annual Meeting
June 6-9, 2010
Auburn, Alabama

Summary: We identified existing equipment for harvesting and/or collecting forest biomass (small trees and residues) and processing the material so it can be utilized for energy production. We conducted a conceptual analysis to see how the basic functions – gathering or acquiring, processing and transport – of each type of equipment compare on a number of measures to those of conceptually ideal examples. Based on these results and other considerations, we recommended areas for potential improvement.

I. Introduction

The threat of wildfire is a major concern in California. The costs of fuel reduction operations, along with other factors, currently limit the amount of forested area that is treated to reduce fire danger. Because of this, the California Department of Forestry and Fire Protection commissioned us to identify equipment – currently in commercial use, under development, or previously tested or used – that can or has potential to be used for harvesting forest biomass; evaluate the costs, production rates and limitations of the identified equipment; and recommend improvements to existing or planned biomass harvesting equipment (Dempster et al. 2008). This paper focuses on recommended improvements, based on empirical results for existing systems and conceptual evaluations of existing equipment and potential changes.

We reviewed hundreds of documents on biomass harvesting operations and equipment, including information from manufacturers and published and unpublished studies. Typically, harvesting activities are classified by activity such as felling, delimbing, bucking, primary (stump to landing) transport, loading, chipping, secondary (landing to utilization facility) transport, etc. But we felt a more basic and useful approach for evaluating equipment concepts might divide these activities into generic categories for which general objectives can be established. Some basic functions include gathering or acquiring, processing and transport. (Gathering could of course also be considered a process.) These functions are in many cases at least partially independent. A feller-buncher gathers (by reaching out and grabbing trees), processes (by severing trees), and transports (by moving trees into bunches). A cable yarder gathers (when choker setters hook logs) and transports (during lateral inhaul and inhaul). Table I tallies some equipment for two example primary activities: extraction and felling.

Table I. Types of biomass harvesting equipment categorized by primary harvesting activity, indicating all associated harvesting activities and machine functions.

		Activities							Functions		
Primary Activity		Comminution	Densification	Extraction	Felling	Loading	Processing	Transport	Gathering	Processing	Transport
Extraction (primary transport)											
	agricultural tractor			x					x		x
	ATVs and smaller vehicles			x					x		x
	brush transport system		x	x					x	x	x
	cable yarder with carriage and chokers			x					x		x
	cable yarder with grapple			x					x		x
	cable yarder, zig-zag			x					x		x
	cable yarder-loader			x		x			x		x
	cable yarder-processor			x			x		x	x	x
	chip forwarder			x							x
	conveyer			x							x
	crawler tractor			x					x		x
	forwarder			x		x			x		x
	helicopter			x					x		x
	prebunching winch			x					x		x
	residue collector forwarder	x	x	x					x		x
	skidder, clambunk grapple			x					x		x
	skidder, cable			x					x		x
	skidder, grapple			x					x		x
Felling											
	chainsaw				x				x	x	
	combi harvester forwarder (harwarder)			x	x		x		x	x	x
	feller buncher, drive-to-tree				x				x	x	x
	feller buncher, swing-to-tree				x				x	x	x
	feller-bundler		x		x				x	x	x
	feller chipper	x	x		x				x	x	x
	feller chipper forwarder	x	x	x	x				x	x	x
	feller forwarder			x	x				x	x	x
	feller skidder			x	x				x	x	x
	harvester				x		x		x	x	x
	harvester, multi-stem				x		x		x	x	x
	tree puller				x				x	x	x

II. Conceptual Evaluation of Equipment and Systems

Good engineers attempt to break large problems into small, functionally independent parts so arrays of simpler solutions may be generated first for the subproblems, then combined and possibly consolidated to develop a more nearly optimal solution to the overall problem. We took a similar approach here, looking at elements of systems (and individual pieces of equipment) rather than complete systems. We are more likely to unearth ways of improving existing systems by dissecting them than by evaluating them as holistic black boxes.

For any activity:

Cost per unit of production* = cost per unit time / production per unit time

* bone dry ton (BDT) or other unit such as cubic foot

Factors that result in low cost per dry ton, given other factors are the same, include:

- Low initial equipment cost
- Long equipment life (in productive hours)
- High utilization rate
- High scheduled time per year
- Low maintenance and repair fraction
- Small crew size
- Large cycle weight, BDT
- Short cycle time

Some of these provide rather obvious ways of improving the situation. For example, scheduled time per year can be increased by operating over a longer season or by double-shifting. Where weight is a possible limiting factor, such as in on-highway transport, dry weight per cycle might be increased by pre-drying of material. But influences of the other factors are not obvious because they are usually coupled: reducing crew size associated with a cable yarder may decrease average cycle weight or increase cycle time. A more revealing approach is needed.

It can be useful to generate conceptual/theoretical ideals for various harvesting activities and then compare the identified types of equipment with ideals to highlight potential areas for improvement. Beginning with the three basic functions – gathering, processing and transport – identified above, we described what might make a machine perform these functions better.

A. Objectives (i.e., more or less is better) for functions

To improve (reduce) the ratio of machine cost to production rate, one should attempt to:

- Maximize the use of the (load-carrying or other weight-unit throughput) capacity of the equipment.
- Maximize utilization of the machine's power, defined as average power output over the duty cycle divided by rated power.
- Maximize work efficiency of the equipment, defined as useful work done over energy consumed.
- Improve the equipment’s utilization rate by minimizing interactive delays.

- Maximize the duty cycles of the components of the equipment.
- For multifunction machines, maximize the parallel (rather than series) operation of functions.

To reduce cycle time:

- Minimize acceleration and deceleration (versus continuous motion).

To reduce crew size for a given level of productivity:

- Substitute sensors and/or machine intelligence and control for human control.
- Minimize the mental complexity of the task so an operator's productivity can be increased.

To maximize utilization rate:

- Minimize interactive delays between activities.

To reduce labor cost per cycle volume:

- Maximize the labor duty cycle (active time per scheduled time)

At the machine or system level, to reduce time and cost per ton:

- Minimize handling or double-handling of material.
- Minimize fixed move-in costs per ton.

To minimize time per ton for in-stand gatherers/acquirers:

- Maximize the area that can be covered per unit time = travel speed * swath width.

To minimize owning costs:

- Maximize equipment life

To minimize operating costs:

- Minimize maintenance and repair fraction

The combination of a taxonomy and organized means of evaluating current methods can provide a logical approach for identifying existing deficiencies and ways to remedy them.

Examples for the Gathering Function

- Maximize the use of the weight throughput capacity of the equipment. Ideal might be a grain combine header; grapples that pick up a constant cross-section of pieces of a given length are good; a shear head that cuts one stem at a time is not good for stems substantially smaller than the machine's capacity.
- Maximize utilization of the machine's power, defined as average power output over the duty cycle divided by rated power. Ideal might be a variable-speed combine, where speed can be increased if crop density is lower.
- Maximize work efficiency of the equipment, defined as useful work done over energy consumed. (Probably not a valid measure for gathering.)
- Maximize the duty cycles of the components of the equipment. Ideal is a machine such as a grain combine in which most components work simultaneously and continuously.
- Minimize acceleration and deceleration (versus continuous motion). Ideal is a constant-velocity combine header or another type of swath harvester. Feller-bunchers (especially drive-to-tree) or loading grapples that start and stop, and move back and forth are not so hot.
- Substitute sensors and/or machine intelligence and control for human control. Ideal might be a load-sensing, constant-power, adjustable-speed combine with height-sensing and

automatic height adjustment. A feller-buncher or loading grapple for which the operator must do all the sensing and manipulate complex controls is at the bottom end.
- Minimize the mental complexity of the task so an operator's productivity can be increased.
- Maximize the labor duty cycle (active time per scheduled time). Ideal is a fully occupied crew, such as a combine operator (or maybe even an operatorless combine).
- For gatherers, maximize the area that can be covered per unit time = travel speed * swath width. Ideal would be a wide swath and high speed, e.g., a two-row tomato harvester is better than a one-row machine if travel speeds are equal. For a tree plantation, an excavator-based feller-buncher that can reach five rows but travels slowly may be as good or better than a single-row harvester that travels relatively fast.

Examples for the Processing Function
- Maximize the use of the weight throughput capacity of the equipment. Ideal might be a chipper being fed a constant, full cross-section of material. Single-stem delimbers aren't utilized fully when tree diameter is below the machine's capacity.
- Maximize utilization of the machine's power, defined as average power output over the duty cycle divided by rated power. Ideal might be a stationery chipper being fed at maximum capacity.
- Maximize work efficiency of the equipment, defined as useful work done over energy consumed: Chippers with sharp knives are efficient; hammer hogs are less so.
- Maximize the duty cycles of the components of the equipment. Ideal is a chipper.
- Minimize acceleration and deceleration (versus continuous motion). Ideal is a chipper. Hotsaw-equipped feller/bunchers are better than intermittent saws or shears.
- Substitute sensors and/or machine intelligence and control for human control. Ideal might be a diameter- and length-sensing processor head, with a matrix of log values by diameter and length.
- Minimize the mental complexity of the task so an operator's productivity can be increased.
- Maximize the labor duty cycle (active time per scheduled time). Ideal is an operatorless chipper.

Examples for the Transport Function
- Maximize the use of the (load-carrying or other) capacity of the equipment. Ideal is a fully loaded conveyer belt; chip vans have good capacity utilization while loaded if cubic volume is not limiting due to low density of material; log forwarders get high marks, skidders get low marks for small trees because grapple area becomes limiting (Figure 34).
- Maximize utilization of the machine's power, defined as average power output over the duty cycle divided by rated power. Ideal is a fully loaded constant-speed conveyer belt, or constant-power belt with adjustable speed; cable yarders do poorly, skidders are in between.
- Maximize work efficiency of the equipment, defined as useful work done over energy consumed. Ideal is a fully loaded constant-speed conveyer belt (or constant-power belt) that raises a load, with a high efficiency drive train. (If there is no lifting, useful work could be zero. An alternative measure would be ton-miles per energy consumed.)

- Maximize the duty cycles of the components of the equipment. Ideal is a machine such as a conveyer in which all components work simultaneously and continuously.
- Minimize acceleration and deceleration (versus continuous motion). Ideal is a constant-velocity conveyer.
- Substitute sensors and/or machine intelligence and control for human control. Ideal might be a load-sensing, constant-power, adjustable-speed conveyer with no operator.
- Minimize the mental complexity of the task so an operator's productivity can be increased. Ideal might be an automated rail system where the operator provides only oversight. The other extreme might involve a machine with a manual transmission traveling around obstacles on rough terrain.
- Maximize the labor duty cycle (active time per scheduled time). Ideal is a fully occupied crew, such as a cross-country truck driver.
- For gatherers that collect distributed material. Maximize the area that can be covered per unit time = travel speed * swath width.

Equipment or system-level examples:

- Maximize the utilization of the components of the equipment. Single-function machines such as feller/bunchers and skidders get higher marks than multiple-function machines such as combination harvester/forwarders unless the multiple functions work in parallel.
- Minimize interactive delays between activities. Ideal is any buffered equipment such as a combine or a conveyer with a large infeed bin and large output storage. Systems with buffers between activities, such as cut-to-length harvesters and forwarders, do well.
- Minimize double-handling of material. Ideal might be a chip van loaded by a chipper so no separate chip loader is needed. An even better example is a chain flail delimber-debarker-chipper. A cut-to-length harvester head is good because it grips a tree only once before conducting multiple operations – felling, delimbing and bucking, but the rest of the cut-to-length harvesting system, which involves handling multiple small pieces downstream of the harvester, is not so good. (Better to leave trees whole for as long as possible so handle fewer pieces. An analogy: Use high-speed, low-torque components as far along a mechanical drivetrain as possible.)
- Maximize the time during which the operator is using the brain. Harvesters do well; chippers with operators do not.
- Minimize the mental complexity of the task so an operator's productivity can be increased. Hand-in-glove or other intuitive controls are preferable than, say, a bank of separate control levers, one for each cylinder or motor on a feller/buncher, harvester or loader.
- Minimize fixed move-in costs per ton. Ideal might be a log truck that has no move-in time. CTL is better than a whole-tree system that involves more equipment.
- Maximize equipment life. Ideal might be a cable yarder because it sits in one place most of the time while working, therefore it sees relatively low wear and tear. A stationary chipper is another good example.
- Minimize maintenance and repair fraction. Ideal might be an irongate delimber. Cable yarders, especially those equipped with clutch-and-brake drivetrains (versus hydrostatic) have low repair costs because of their relatively static locations and simple drivetrains.

B. Limits on throughput/productivity

Another way of gaining insight about equipment capabilities is to look at what limits a concept's throughput, especially when dealing with smaller stems to be addressed in fuel reduction operations. Some of the more obvious limits:

- Power. This obviously limits production for most equipment at some point in the production cycle, but in most cases is not limiting for smaller trees.
- Diameter capacity. Many pieces of equipment – feller bunchers, harvesters, processors and chippers, for example – have upper limits on the diameters of trees or logs they can handle; a few such as grapples have lower limits, but the lower limits may not come into play very often because the equipment will handle multiple small stems or logs.
- Weight capacity. Log trucks and chip vans are limited by legal weight restrictions; other equipment such as swing-to-tree feller bunchers or loaders are limited by design to maximum loads that vary with reach.
- Volume capacity. Chip vans may be limited by cubic volume capacity rather than legal weight if the bulk density of the chips or other material being handled is low. Volume limits are more restrictive for small trees and residues because of their lower bulk density.

Other limits are less obvious but very important when utilizing given equipment for a range of tree sizes.

- Length throughput capacity. Some equipment, such as a ring debarker for a sawmill, processes single logs at a fixed linear speed. Therefore if the average log diameter drops by a factor of two, the volume throughput of the debarker drops by a factor of four.
- Cross-section area handling capacity. Some equipment is limited by the area of material it can hold or process. For example, a grapple skidder is limited by the area of its grapple opening in situations where power or pull are not limiting. Volume-handling capacity per turn is therefore proportional to length of the trees and is less for smaller trees.
- Piece throughput capacity. A non-accumulating feller/buncher is a good example of a piece handler. It can cut a relatively fixed number of trees per hour independent of tree size. Since tree volume is roughly proportional to the cube of tree diameter, volume-handling capacity of this type of equipment may drop by up to a factor of eight when the average tree size is decreased by a factor of two.

Machines that can operate at their weight capacities or power limits whether trees are large or small might be considered ideal configurations. Those that handle a relatively fixed number of pieces per time are clearly the worst for dealing with a range of tree sizes. One of the biggest challenges and opportunities for developers of new equipment is to shift from piece-handlers and other configurations that are piece-size sensitive, to designs that can handle small trees as effectively as larger ones. The measures of the various objectives and limits are summarized in Table II.

C. Example Evaluation

We used this evaluation procedure to compare types of equipment that carry out similar activities. For example, from Table I we selected three felling-only machine categories:

chainsaw, drive-to-tree feller buncher and swing-to-tree feller buncher. We added a variation – a hot saw cutting head versus an intermittent cutting head such as another type of saw or a shear – as another option for the swing-to-tree machine. As a "close to ideal" machine we also included a prototype harvester – the Hyd-Mech FB-12 – developed under contract to the National Research Council of Canada in the 1980s to harvest energy plantations of single-stem short-rotation woody crops such as poplar or sycamore, of up to 12" butt diameter. The Hyd-Mech was intended to harvest straight rows of trees on relatively flat ground so the concept is not directly applicable to most fuel reduction operations.

We then assigned values (0 = worst possible, 10 = best possible) to each of the first ten measures listed in Table II for each of the three functions (with the exception of transport for the chainsaw which is not generally used to bunch trees) and for the overall machines. The results of this example evaluation are displayed in Figures 1 through 4. They show substantial differences between the types of equipment on certain measures, helping identify potential areas for improvement to existing equipment.

Table II. Matrix of measures of objectives by function.

	Function			
Measure	Gather	Process	Transport	Overall Machine
Use of (load weight-carrying or other throughput) capacity	x	x	x	x
Utilization of machine's power	x	x	x	x
Work efficiency		x	x	x
Duty cycles of components	x	x	x	
Parallel use of components				x
Acceleration and deceleration	x	x	x	x
Sensors/machine intelligence vs. human control	x	x	x	x
Mental ease of the task	x	x	x	x
Labor duty cycle	x	x	x	x
Area covered per unit time	x			x
Interactive delays				x
Handling/double-handling of material				x
Fixed move-in costs per ton				x
Equipment life				x
Maintenance & repair fraction				x
Limits (Weight, Volume, Area, Length, Piece)	x	x	x	

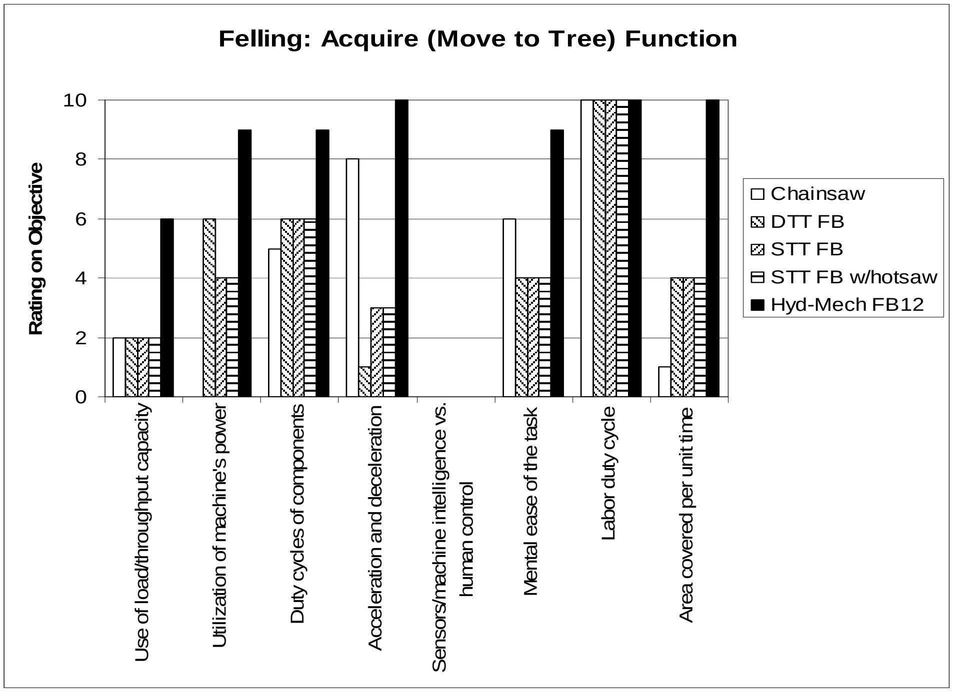

Figure 1. Comparison of the efficacy of five different types of felling equipment for several measures related to the move-to-tree function.

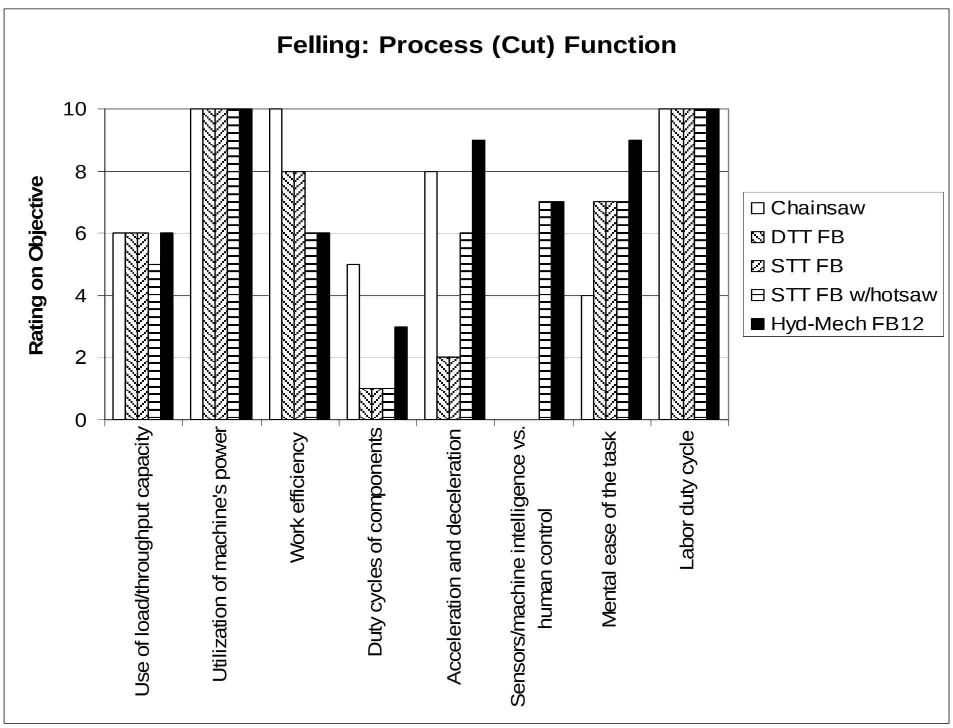

Figure 2. Comparison of the efficacy of five different types of felling equipment for several measures related to the cut function.

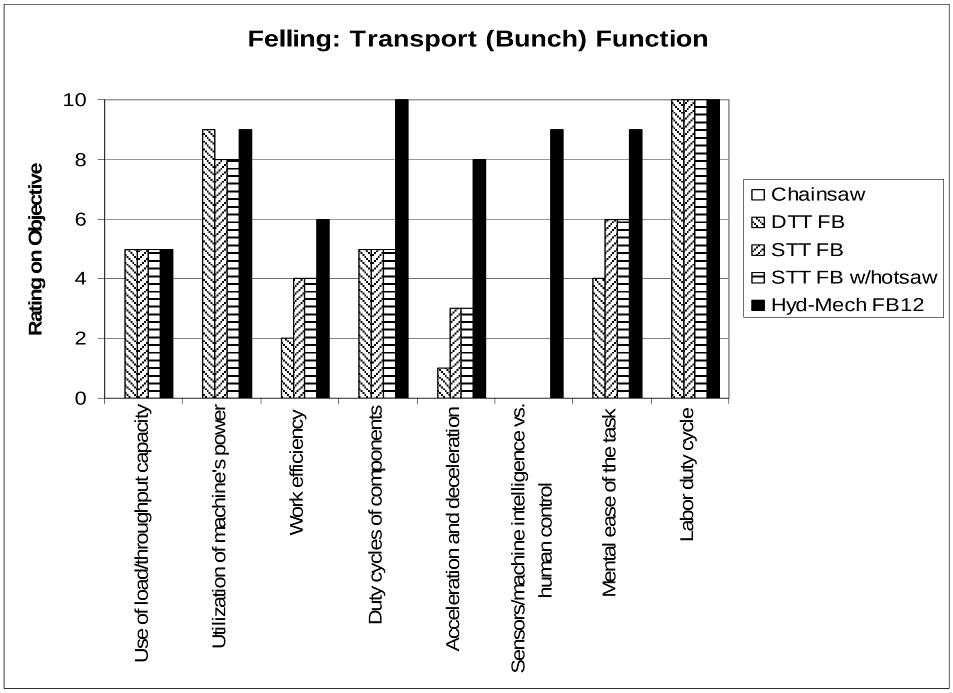

Figure 3. Comparison of the efficacy of five different types of felling equipment for several measures related to the bunching function.

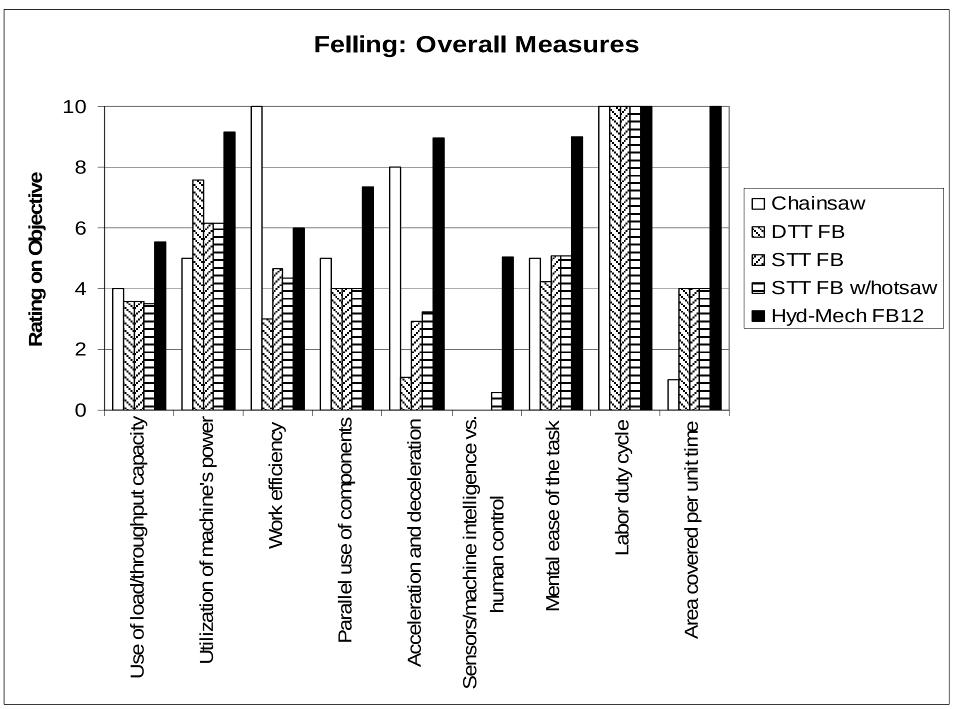

Figure 4. Comparison of the efficacy of five different types of felling equipment for several measures related to overall machine operation.

D. Design Principles

When designing a system from scratch or trying to improve on an existing system, it is beneficial to begin with a set of basic design principles, somewhat in parallel with the objectives mentioned previously. We suggest the following, to be used in identifying areas for improvement in existing systems.

1. Use the human brain and machine brawn. A person can generate on the order of a fifth of a horsepower for long periods. If the cost of that person with overhead is $30 per hour, the cost per unit of power output is well over $100 per horsepower-hour. In contrast, a 200-Hp skidder has an hourly cost, including operator, of approximately $100, for a cost per unit of power of well under $1 per horsepower-hour. Activities that require substantial power, such as moving wood, clearly should be carried out by machines rather than humans. Systems such as zig-zag yarding systems that require humans to move wood are working at extreme economic disadvantages. In addition, as a skidder is reduced in size and approaches the zero end of the power scale, it approaches the human cost-to-power ratio. This is one reason the optimal size of machine does not decrease in direct proportion to the size of the trees or logs being handled.
2. Take advantage of economies of scale. In most cases, the capital and operating costs of equipment do not increase in direct proportion to size, so the cost per capacity decreases as capacity increases. To give a simple example why, consider a spherical tank. The volume of the tank increases with the cube of its diameter. The material needed to fabricate the tank is mostly in the shell, but the surface area of the shell increases with only the square of the diameter rather than the cube. The moral is: use higher capacity equipment if the capacity can be reasonable well utilized.
3. Fully utilize payload weight capacities, in contrast to volume capacities. For energy feedstock, value is based on energy content. For woody biomass of a given moisture content, energy content depends on weight, not on bulk volume. The energy content per weight may be increased by drying or by converting to another material such as bio-oil.
4. Densify on-highway loads, to a point. Transport is constrained by several legal limits including gross weight. Vehicle height, width and length also are limited, and the product translates into a volume limit. While permits can be purchased for special cases where the limits can't be met, the associated costs make these economically unattractive for everyday operatioons. Standard vehicles have rather uniform tare weights and cubic volume capacities. For example, a chip truck might have a payload limit of 50,000 lb (80,000 lb gross limit – 30,000 lb tare) and a volume capacity of 2700 cubic feet (100 cubic yards). The weight limit can therefore be reached if the material bulk density is about 18.5 lb/ft^3 or greater. Based on reported densities for various materials (Figure 43), it's clear that some materials such as pellets are over-densified for transport in a standard chip van, while others such as uncomminuted slash exact a large penalty in payload and therefore should be densified prior to transport.

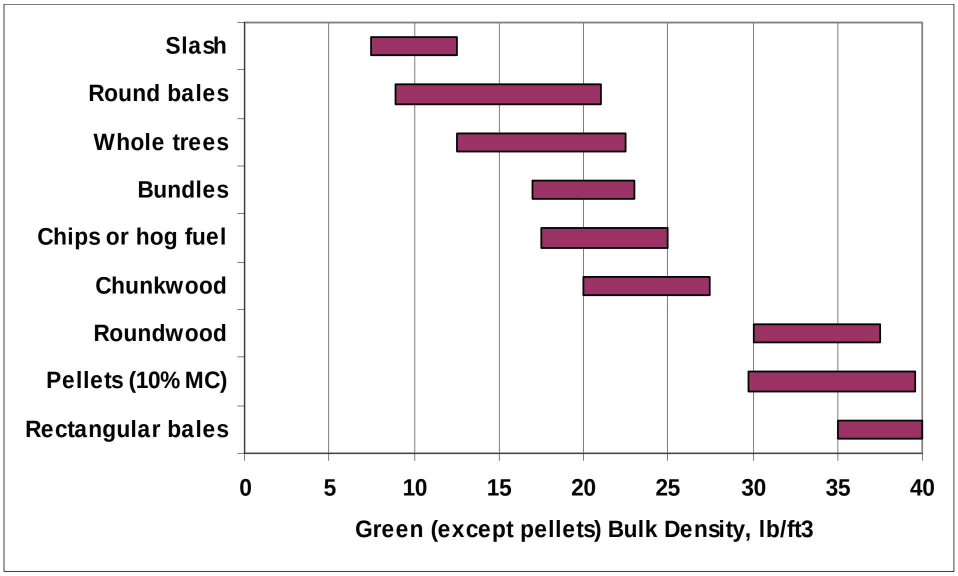

Figure 5. Density of various forms of woody biomass, assuming 50% moisture content, wet basis, except for pellets (10% moisture content).

5. Handle small pieces in bulk or in big packages. Piece-handlers require approximately the same amount of time to handle each single piece, independent of piece size. For example, a fork transports a piece of pizza to the mouth in the same amount of time, no matter whether the piece is a half-inch square or four square inches. A feller-buncher is somewhat similar, although accumulators allow the handling of more small pieces before bunching. Since tree volume (and weight if solid density is constant) is approximately proportional to the cube of diameter, the weight handled per time diminishes dramatically as tree diameter decreases. Length handlers such as ring debarkers or stroke delimbers have an approximately constant linear throughput rate. Volume (and weight) throughput is proportional to length times cross-sectional area, so it is proportional to the square of diameter. Area handlers such as grapple skidders transporting small trees are limited by the cross-section area of the grapple: more small trees than larger ones can be held in the grapple. Volume, however, is the product of length and area, and tree length for small trees may increase in almost direct proportion to diameter. Volume handlers such as forwarders are limited by the width of the bunks, height of the stakes and lengths of the relatively short logs loaded, all of which may be independent of tree diameter. The weight on a forwarder, however, will depend on the bulk density of logs. Weight handlers are ideal because they are insensitive to either piece size of bulk density. A barge, for example, can in theory be loaded until its weight limit is reached. Materials of lower bulk density can be accommodated by adding relatively light side panels to the barge.
6. Minimize rehandling. When possible, avoid setting down and picking up pieces multiple times. A cut-to-length system may handle the same piece four times before the material is in a chip van: once by the harvester, twice by the forwarder (loading and unloading) and once by the chipper. In contrast, a harvester-chipper-forwarder cuts, chips and blows material into a chip container while handling each tree only once.

7. Fully utilize humans, machine power and machine components. Ideally the duty cycles for all elements of a system should be 100% on. A conveyer belt is a good example to emulate. Traditional cable yarding represents a case where neither the labor nor machinery is very well utilized because of interactive delays between the elements of the yarding cycle: outhaul, lateral outhaul, hook, lateral inhaul, inhaul, and unhook. The issue of utilization of components is critical for multifunction machines. The ideal situation, and therefore where a multifunction machine is attractive, utilizes all functions simultaneously. A delimber-debarker-chipper is a good example. In contrast, a machine where the functions act sequentially, i.e., only one at a time, has difficulty competing with a multi-machine system because the multi-function machine is almost certainly more expensive than any of the single-function machines of the same capacity. Early combi harvester-forwarders were good examples because they operated at any one time as either a harvester or a forwarder. Such machines have lower move-in cost than a multi-machine system, but this is only beneficial for very small treatment units.
8. Move continuously rather than starting and stopping. If a machine has a fixed maximum speed, it can cover a given distance faster if it doesn't repeatedly start and stop. In addition, acceleration requires energy; some energy available when decelerating is lost to heat when braking, so each start-stop cycle has a net energy cost.
9. Use humans to make decisions and take actions that cannot be automated; use computers to deal with other decisions/actions. Some decisions require information on multiple parameters, and evaluation algorithms that may be difficult to automate. Selecting which trees to be cut in a fuel-reduction treatment in a naturally regenerated stand is a good example. Other activities may be easier to carry out with a "robot", e.g., moving cut trees to a bunch or bunk, or processing a cut tree.
10. Recognize that tradeoffs almost always exist. It is usually impossible to simultaneously optimize all of the multiple objectives; a gain in one area may be offset by a loss in another. Weighting of multiple objectives – especially by combining into a single objective function such as maximization of net worth – is a clear approach when feasible. But the overall optimum may depend on the specific situation. Take the narrow issue of cost per green ton of skidding versus forwarding as an example. Skidders travel faster, both empty and loaded, and require less time per ton to load and unload. They also have lower capital and hourly costs, but carry much smaller payloads than do forwarders when handling small trees. Because of the tradeoff between payload and other factors, skidding is less expensive at shorter distances, while forwarding is cheaper at very long distances.

III. Base Case Systems and Possible Changes

We developed stump-to-truck costs for some "base case" systems, then considered some possible modifications to each. For simplicity, we confined this evaluation to biomass-only trees, assuming they will be comminuted before conversion into a final energy product. Two of the base cases[1] for relatively gentle terrain are:

[1] A delimber-debarker-chipper (DDC) can be substituted for the chipper if bole-only chips are required for purposes such as pellet production. The residues (bark and branches) produced by the DDC can be comminuted by a tub grinder for use as feedstock for another process.

1. Whole Tree, consisting of a combination of swing-boom feller-bunchers and grapple skidders, and a chipper at the landing
2. Cut-to-Length (CTL), consisting of a combination of harvesters and forwarders, and a chipper at the landing

A. Results for Base Cases, from Empirical Studies

We collected information from numerous empirical studies on the production rates. With this and related information such as repair and maintenance cost estimates and utilization rates (Brinker et al., 2002), we used the Fuel Reduction Cost Simulator or FRCS (Fight et al., 2006) to estimate costs over a range of tree size (4”-10” dbh) that is relevant for fuel reduction operations and generally below what is currently merchantable in California. Other values such as skidding distance were held at typical values.

For swing-boom feller bunchers, productivity changes by a factor of three or so over the range of tree size (Fig. 6) due to the piece-handling character of the functions associated with the boom. Unlike move-to-tree machines, the undercarriage travel for swing-boom machines is not piece-related, accounting for a lower sensitivity of productivity to tree size.

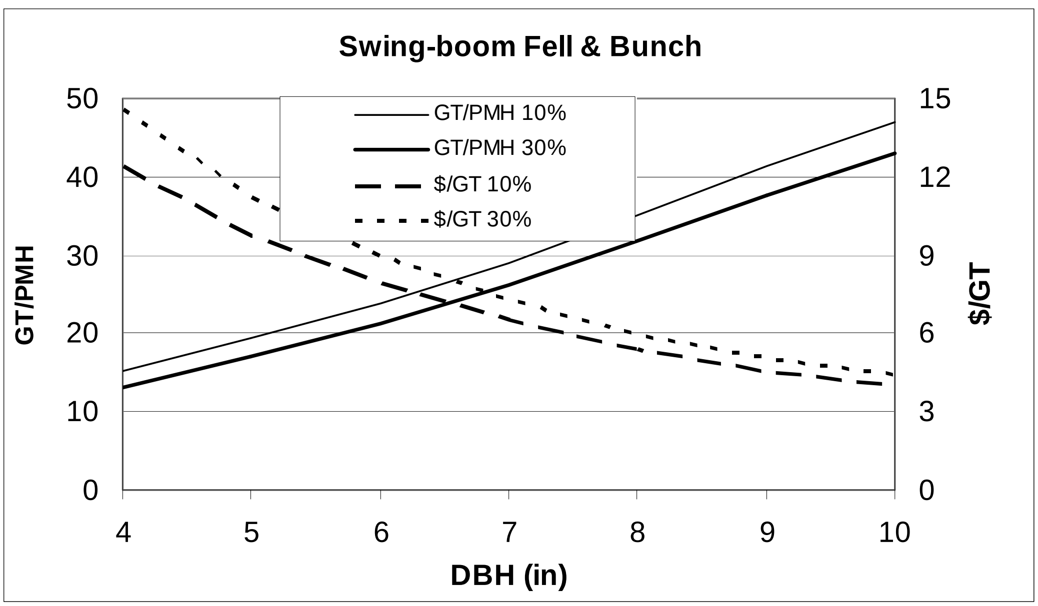

Figure 6. Representative productivity and cost of swing-boom feller bunchers versus tree size and slope.

The productivity of skidding of bunched trees is rather insensitive to tree size; our representative cases show an increase of only 30-40% across the 4-10” range of tree size (Fig. 7). This is true because skidders do not handle individual trees; they pick up bunches and transport grapple loads of multiple trees. For larger trees the load weight may be power-limited; for smaller ones it is constrained by the cross-sectional area of the skidder’s grapple, but skidders can compensate for smaller loads somewhat by traveling at higher speeds, also allowing them to operate near a power-limited condition while loaded.

For skidders, loading and unloading times are relatively short, the former effect being a result of the mechanized bunching (a full load might consist of as little as a single bunch) and the latter due to the simplicity of dropping a skidded load from a grapple. As a consequence, total skidding time per load is close to directly proportional to skidding distance, other factors being equal. To illustrate, for the 10” trees and 10% slope case and 500-ft skidding distance, loading and unloading represents only about a quarter of the cycle time, and only about a minute per green ton. As explained later, this contrasts with the case for forwarding.

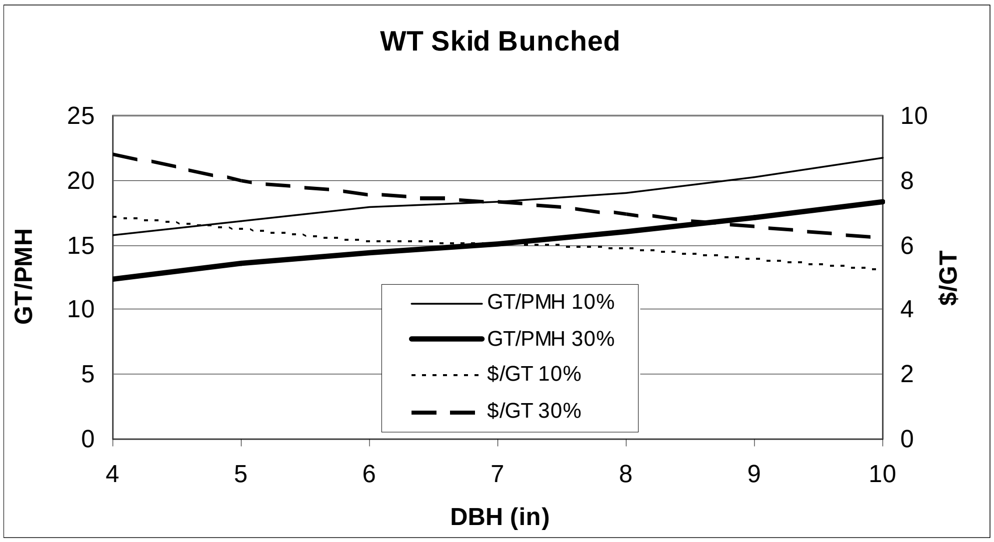

Figure 7. Representative productivity and cost of skidding bunched whole trees versus tree size and slope.

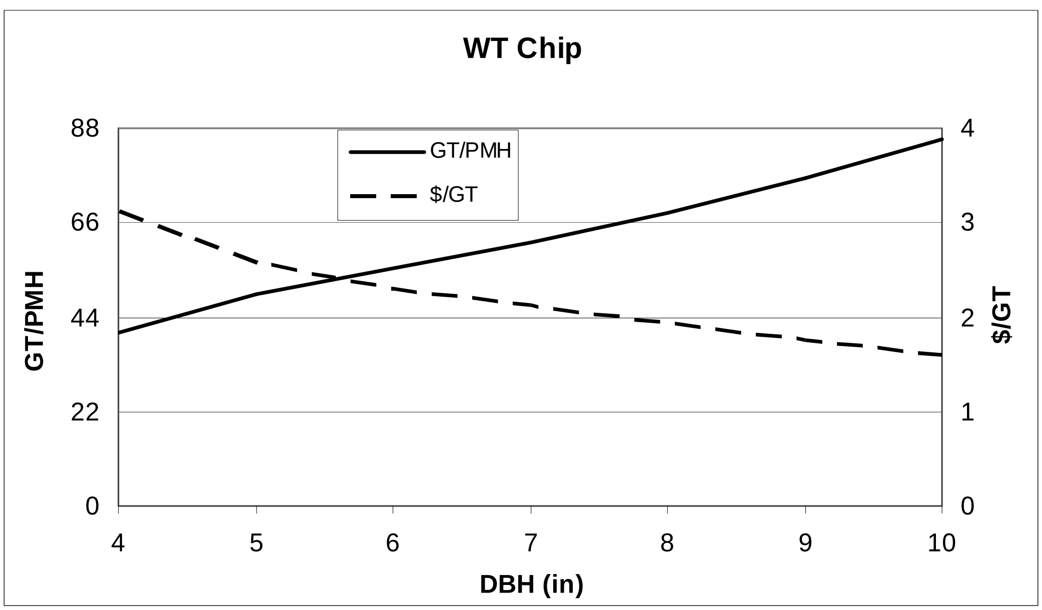

Figure 8. Representative productivity and cost of chipping whole trees versus tree size.

Based on the limited number of empirical studies considered, chipping productivity approximately doubles across the considered range of tree size (Figure 8). In concept, chippers are limited by either cross-sectional area of the material being fed or by machine power, so little sensitivity to tree size might be expected. However, many more small trees must be fed to achieve the same feed rate in terms of weight (approximately ten 4” trees to equal one 10” tree), so the operator and infeed grapple capabilities are more limiting than power for the smaller trees.

Cut-to-length harvesters are sensitive to tree size, with productivity increasing by a factor of six across the range of tree size (Figure 9). Harvesters share this sensitivity with other felling methods and for similar reasons: the acquire and fell functions are piece-handling rather than volume- or weight-limited. The rate of processing (delimbing and bucking) is generally limited by a linear throughput speed, with stops for each bucking cut. As volume and weight throughput are more affected by diameter and cross-section than length, the processing rate is also relatively sensitive to tree size as indicated by DBH.

Processing accounts for a substantial portion of each harvesting cycle. The above results apply to single-tree harvesters, on which all included empirical studies were based. Some relatively new multi-stem harvesting heads have the potential to increase production rates for small trees.

The productivity of CTL forwarding increases relatively little – by a factor of about 1.5 – from the small end to large end of the range of tree size (Figure 10). This is a result of the CTL harvesting activity, which converts trees of all sizes to logs of uniform length. Because forwarders can be fully loaded with small logs or large logs, the travel empty and travel loaded elements of each cycle are not affected by tree size. Only the loading and possibly unloading involve handling of the logs by the boom and grapple. When loading, it is generally easier to pick up more weight in a single grapple load if the logs are larger, so loading is somewhat affected by average log size and therefore tree size. Unloading is not impacted greatly by log size because the logs to be unloaded are neatly compacted within the bunks of the forwarder.

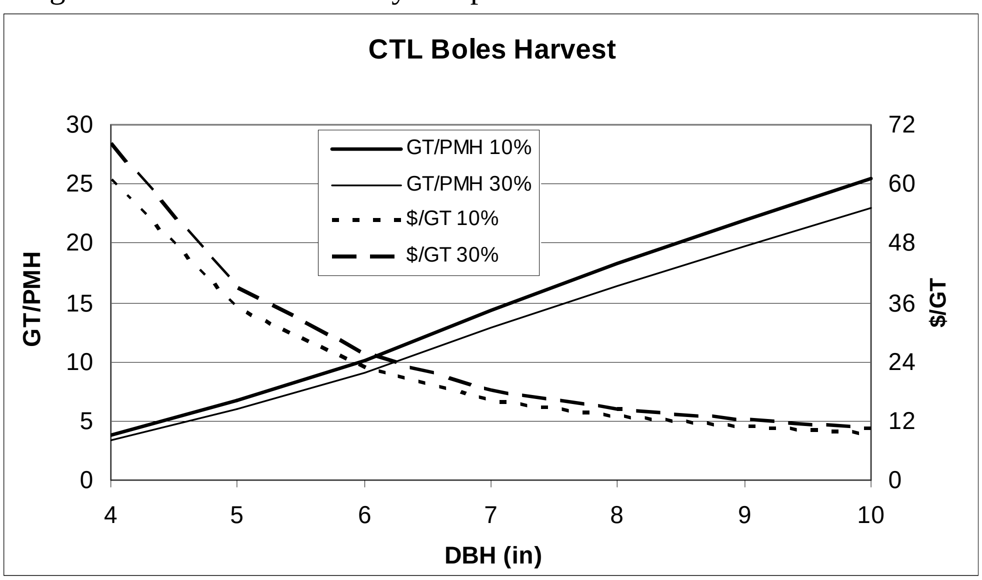

Figure 9. Representative productivity and cost of felling and processing with a cut-to-length harvester versus tree size and slope.

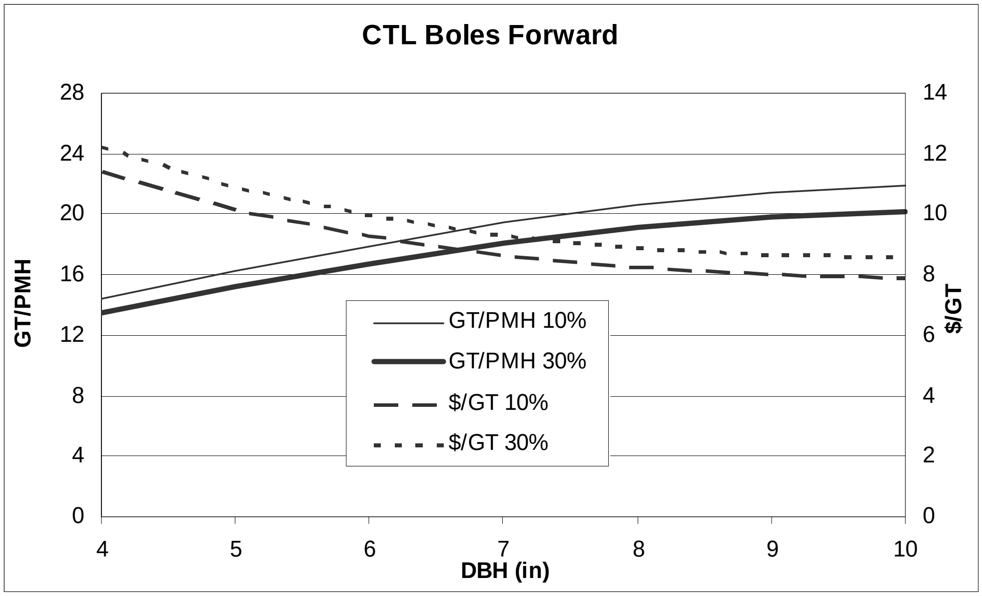

Figure 10. Representative productivity and cost of forwarding cut-to-length logs versus tree size and slope.

Unlike skidding, the time to forward a load increases much less than proportionally with travel distance within the typical operational range. This is a result of the substantial "terminal" times involved with loading and unloading, each of which requires at least several and in some cases dozens of grapple loads. For the 10" trees and 10% slope case (at forwarding distance of 500 ft), loading and unloading account for roughly two-thirds of the total cycle time, and approximately two minutes per green ton.

Several factors affect the overall productivities and costs of skidding and forwarding: loading and unloading times, load sizes (generally four to six times as large for forwarders than with skidders), travel speeds (slower for forwarders) and hourly costs (30-50% more for forwarders than for skidders of similar power). In general, forwarding cost per ton is less sensitive to distance than is skidding cost (due primarily to the much larger load size), but forwarding is costlier than skidding at short distances (due to the large loading and unloading time per ton). For our representative case with 10" trees on 10% slope, skidding and forwarding break even at a rather long one-way travel distance of about 1500 feet.

B. Changes to Whole Tree Systems

Continuous-Travel Feller Buncher

Deficiencies addressed: Piece-handling nature of feller bunchers; start-stop action of feller bunchers; need for the operator to continuously control the boom.
Continuous-travel machines have been developed for short-rotation willow plantations and are extremely productive. In trees of 2-3" dbh, these machines may fell (and chip) on the order of 50 green tons per hour of travel down the crop rows (Hartsough and Spinelli, 2002). This shows that productivity does not have to be low for small trees, if the trees are handled "in bulk" rather than

as individual pieces, and if the machine travels continuously rather than starting and stopping at each tree. Clearly, fuel reduction thinnings of natural stands are not harvests of even-aged short-rotation plantations: trees must be selected from either side of the skid trail as well as from within the trail, and are not located on uniform or otherwise predictable spacing. But the trees are substantially larger than in willow plantations, so fewer must be cut. For example, if trees average 200 green pounds (about 5” dbh), cutting eight per minute will produce about 50 GT/hour. How might this be accomplished? A first step in this direction might be boom-tip control, where the operator indicates where the felling head should go rather than controlling multiple boom functions, speeding up felling somewhat. In a semi-automated system, the machine operator might select trees to be cut by “painting” them with a laser. A target rate of eight per minute is certainly within the range of human capability. Given the known locations of the standing tree and the trail, the machine’s computer would then direct the boom out, cut the tree and bunch it. Proximity sensors on the head could be used to help avoid hitting leave trees. A machine equipped with two booms and felling heads, should be able to keep up with the operator’s designation rate.

A more advanced automation scheme might allow the operator to select the leave trees, typically fewer than those to be removed in a fuel reduction operation, and sense and remove the rest. Such technology is not available in the woods yet, but the elements have been demonstrated on equipment such as the vehicles competing in the DARPA Challenge. To demonstrate the possibilities, we assumed a feller buncher with two upper limits: 1 mile per hour travel speed, and 1000 trees pre PMH, cutting 30 feet on either side of the trail centerline. We assumed the hourly cost would be twice that of a conventional self-leveling swing-boom machine. Based on these results, we estimate the potential benefits to be on the order of $2-4/GT.

Long-Reach Swing-Boom Feller Buncher

Deficiencies addressed: Under-utilization of expensive booms.

Machines must be designed for the worst-case scenario, whether that be the largest tree or steepest slope it must address. In the case of boom-equipped machines, load requirement at maximum reach is also a worst-case scenario. U.S.-manufactured feller bunchers commonly reach only 25 feet or so, while harvesters may reach 30 or 40 feet or more. (Most harvesters don’t hold trees upright, so they can get by with rather slender booms.) A Japanese research group, however, developed a feller buncher for thinnings that could reach over 60 feet and fell trees up to 16” at the butt (Parker, 1999). It accomplished this by using an intermediate foot between the inner and outer sections of the boom. Another approach might employ a caster wheel at the end of the boom to support the felling head, thereby eliminating much of the moment on the boom and carrier. This would either result in a slimmed-down and somewhat less expensive machine for the same reach, or a longer reach for the same cost. Such a machine would allow trails to be located at wider intervals, and for larger bunches to be made for skidding. The longer reach and wider trail spacing would be especially beneficial when pairing a feller buncher with a cable yarder, due to the significant fixed cost of moving the yarder from one corridor to another.

Feller-Skidder

Deficiencies addressed: Repeated handling of trees by the feller buncher and skidder.

As for a combi harvester-forwarder (harwarder) versus a two-machine harvester and forwarder system, a combination feller-skidder cannot have a cost benefit on relatively large treatment units unless the multifunction aspect eliminates some activity that would otherwise be carried out by separate feller bunchers and grapple skidders, or conducts activities in parallel. Time eliminated might include part of what a feller buncher spends moving trees to create large bunches for a skidder, as all trees could now be dropped directly into the skidder's clambunk grapple. Loading times for conventional skidders are so short that any reductions here are likely to be negligible, and the activities – felling and skidding – would essentially be carried out sequentially rather than simultaneously, assuming current felling technology. The machine is more expensive than either a feller buncher or a skidder.

Improved felling technology, as hypothesized above for the continuous-travel feller buncher, might make a combined feller-skidder more attractive by allowing the felling and travel activities to occur simultaneously rather than in sequence. The machine would travel empty to the end of the trail, turn around and cut while traveling back to the landing. But higher hourly cost for the automated felling capabilities would make this a very expensive skidder, so we doubt this concept has much potential.

Selective Feller-Chipper-Forwarder (paired with separate Chip Forwarder at longer distances)
Deficiencies addressed: Repeated handling of trees by the feller buncher, skidder and chipper; underutilization of the weight capacity of the skidder when handling small trees; interactive delays between machines when buffers run out.
The tradeoffs with a multifunction feller-chipper using current technology did not justify this combination when trialed in the form of the Chipset chip harvester in Finland during the mid-late 1990s (Asikainen, 2004). While the felling and chipping activities could in theory operate simultaneously, the piece-handling-limited felling productivity was considerably less than the capacity of the chipper. The Chipset was capable of handling material up to about 14" diameter, but sound whole trees of that size would not have been chipped for fuel in Scandinavia because of their higher value for other products. In California, larger trees (although not 14-inchers) would be chipped for energy, so the felling productivity might more nearly match the capability of the chipper. The Chipset is no longer in production, but a similar machine, the Valmet Combi BioEnergy, has been introduced recently. We have no definitive literature, but some information indicates production rates might be on the order of 5-10 bdt per hour for this 190-Hp machine (Siuro, 2007, Biologistiikka Oy, 2005). If production has been limited by felling very small trees and processing many of them into more valuable roundwood rather than chipping them, the production potential could be substantially higher under California conditions, i.e. where somewhat larger trees would be chipped. But one study would indicate the rates above are near values observed for landing-based chippers of similar power (Johnson, 1989).

While we do not have a good cost estimate, the machine must be more expensive than a feller buncher, chip forwarder or chipper of equal capability, but almost certainly not as expensive as three separate machines. And it has only one operator. If felling and chipping can both be productive, the cost per ton might be less than that for two separate machines, and since chip forwarders carry full loads regardless of the sizes of the trees, the primary transport would be rather efficient. The Valmet literature indicates a time of 3 minutes to transfer chips from the feller-chipper to the forwarder (Biologistikka Oy, 2005). Assuming a similar time to offload to a van and a payload of 6 bdt (12 GT) in the 35-yd3 container, the terminal times are only a half minute per green ton, better than for a grapple skidder with small trees, and substantially better than for a log forwarder. Travel times should be similar to those for a log forwarder, making the extraction cost rather low. Our cost calculations, based on the rather fuzzy data available to us, show no advantage over the base-case system, but this option warrants more attention as subsequent information on the Valmet Combi BioEnergy and similar machines becomes available.

Given the type of multifunction machine, when the felling device is broken, the chipper is idled, and vice versa. Interactive delays of some kind between the primary machine and the chip forwarder are unavoidable: the only buffer between the two is the on-board bin. While the chipper can forward if the forwarder is down, the forwarder can not accomplish anything when the chipper is down.

Chip forwarders have rather high centers of gravity, as do log forwarders, so they are restricted to travel up and down the fall line on steeper terrain. Log forwarders have been used successfully in California and certainly in the Pacific Northwest, so chip forwarders might be able to access a substantial part of the area designated for ground-based fuel reduction operations.

Selective Feller-Grinder-Forwarder (with a separate Chip Forwarder at longer distances)
Deficiencies addressed: Inefficient handling of small trees, brush and slash by means of a boom and grapple; multiple handling of material.
Masticators can process slash and standing material. A mesquite biomass combine on a 135-Hp tractor produced 4-5 (assumed green) tons/hour while processing and forwarding trees up to 6” diameter at speeds up to 2 mph (Ulich, 1983). The productivity of the prototype NCSU/FECON harvester (FTX440 base, 440 Hp engine, FECON Inc., 2008) while processing understory vegetation has improved with experience (Roise et al., 2009). Density of overstory trees has been the key factor affecting productivity, with higher production rates in stands that are more open and therefore allow the harvester to travel on a straighter trajectory.

These machines point towards the possibility of using similar equipment in California in fuel reduction applications where masticators have been employed in the past. Fixed-head masticators are easier to convert, but excavator-mounted heads are more common in California, however, because of obstacles and uneven terrain. Adapting these for collection would be more complicated because of the circuitous path that must be followed by the material from the head, along the boom and back to a container. The Valmet Combi Bioenergy feller-chipper-forwarder uses a pneumatic system rather than kinetic energy of the chip to transport chips along a multi-angled path. The same approach might be used for masticated material.

Grapple Skidder with Large Grapple
Deficiencies addressed: Underutilization of the weight capacity of the skidder when handling small trees.
Small trees are short. To get the same weight of small trees in a skidded load, more basal area must be carried. Since trees must generally be grappled by the butts to avoid breakage, the only way to get more trees in a grapple when it is already full is to increase the size of the grapple. There would be a slight payload weight penalty to pay with more iron, but not a substantial one.

We ran a simple simulation of a larger grapple by assuming a combined hourly cost and/or cycle time penalty of 10%, and a payload advantage of 100% for trees of no weight, diminishing to no payload advantage for 1-GT trees. Based on this simple model, the cost advantage might be approximately $1-2/GT.

Clambunk skidders may have much larger grapples than do conventional skidders, but these grapples are inverted and therefore require a separate loading boom and grapple on the machine to transfer trees from the ground to the clambunk. This increases loading (but not offloading) time per ton substantially compared to that for a regular grapple skidder, and therefore the fixed cost per ton, versus the variable cost that increases with skidding distance. The latter is rather low for a clambunk because of its large load, so in a fashion somewhat similar to that for a short-log forwarder, a clambunk skidder out-competes a regular skidder at longer distances. The breakeven distance is shorter for a clambunk than for a short-log forwarder because the former's loading and (especially) unloading times are so much less.

Whole-Tree Forwarder

Deficiencies addressed: Underutilization of the weight capacity of the skidder when handling small trees.

A standard-configuration skidder with a large grapple has both advantages and disadvantages compared to a whole-tree forwarder. The center of gravity of the load is near the ground, so the machine is relatively stable on slopes. Loading time is very short if an adequate number of large bunches can be reached, but it may be difficult to assemble an adequate load. The skidder dragging a large number of stems may cause some damage to reserve trees, and of course sweeps organic matter off the skid trail. On the other hand a forwarder long enough to hold whole trees would have difficulty turning around or backing down a trail. Existing whole-tree forwarders are used in clearfell operations where backing and sharp turns are not necessary. One option might be to piggyback a trailer with rear bunks onto the front bunks, using either the loading grapple as on a self-loading truck or a hydraulic device such as that used on some logging trucks in Australia.

Chipper-Forwarder (paired with a separate Chip Forwarder at longer distances)

Deficiencies addressed: Repeated handling of trees by the skidder and chipper; underutilization of the weight capacity of the skidder when handling small trees; interactive delays between the skidder and chipper when buffers run out.

Chipper-forwarders have been in existence for a considerable time; Wellwood (1979) mentioned machines with containers capable of carrying 4-6 tonnes, and producing 4-8 green tonnes/hour. Biomass for energy from forest thinnings in Denmark is almost exclusively produced by chipper-forwarders (Molbak and Kofman, 1991). Spinelli and Hartsough (2001a) reported results for small chipper-forwarders. Pottie and Guimier (1986) cited a study that found a Bruks 1000CT drum chipper (160 kW, on a 100-kW forwarder chassis) to be twice as productive at the landing as when processing residues on a cutover: 5.6 versus 2.8 odtonnes/PMH. (The issue of bringing residues to the landing was not considered in this comparison.) Mitchell et al. (1989) studied thinning of young stands in Great Britain. Chipping and extraction costs for a stand-mobile chipper-forwarder were only 30% of those for skidding whole trees and chipping at roadside, apparently due to underutilization of the load capacity of the skidder when dealing with very small trees, and underutilization of the chipper at the landing because of the low skidding productivity. Because of economies of scale, larger machines are preferable if they can be fully utilized. Silvatec (2005) produces a 278-Hp chipper-forwarder with a 16-m^3 bin, capable of chipping material up to 35cm in diameter. Logset (no date) previously manufactured a 360-Hp chipper with 17-m^3 side-tipping bin that could be mounted on Logset forwarders. It also had a diameter capacity of 35cm.

A combination chipper-forwarder, following a feller buncher, should have most of the advantages of the feller-chipper-forwarder while avoiding the disadvantage of having to closely match the productivity of the felling and chipping functions on the same machine. Trees can be felled well in advance of chipping, eliminating interactive delays between the machines. It has for some time been considered the most promising in Denmark for biomass thinning (Suadicani, 1989, cited by Twaddle et al. 1989). Our simulations, however, showed it to be less advantageous than either the base-case system or a combination feller-chipper-forwarder. Relative to the latter, the chipper-forwarder performed comparatively well for the smallest trees we considered because felling was more limiting than chipping. For 10” trees, however, we believe that felling would be as rapid as chipping, therefore putting the felling head on the chipper-forwarder may not impact productivity.

Selective Feller-Bundler

Deficiencies addressed: Repeated handling of trees by the feller buncher, skidder and chipper; underutilization of the weight capacity of the skidder when handling small trees; interactive delays between machines when buffers run out; degradation of chips during long-term storage. A prototype feller-bundler is under development in Finland for very small trees. Substantial upsizing would be required for California conditions. Bundling is more costly than direct chipping, but can be advantageous if seasonal operations require long-term storage and the material degrades substantially if in chip form.

C. Changes to Cut-to-Length Systems

Harvester with Multi-Tree Head

Deficiencies addressed: Low utilization of the capability of the harvester’s processing capability (a length-handling device) when dealing with small stems.

The machine cuts multiple smaller trees before processing them, thus saving considerable processing time. Lilleberg (1990) found that processing time per tree decreased by about 40% when two trees were processed rather than one, and by 50% when three or four were handled rather than one. Bergkvist (2003) reported a study of a single-stem head that had been modified for multiple trees. When felling and processing trees of approximately 0.06 m^3 (2ft^3), the multi-stem capability increased productivity by 36% (trees per hour) and 18% (volume per hour, because trees processed while in the single-stem mode happened to be slightly larger). Gingras (2004) tested a Waratah HTH-470HD head with trees averaging 0.10 m^3 (3.5ft^3). Harvester productivity increased by 21-33%, and the head handled multiple stems on 30-40% of the cycles. Other European studies have reported on multi-stem feller buncher heads for very small trees harvested for energy. The concept is common in the U.S., but the European heads are designed for harvester booms, so we feel the results in terms of trees handled would be similar for multistem harvester heads. Kärhä et al. (2005) tested the Narva-Grip 1600-40 (Pentin Paja Oy, no date). Between 73% and 96% of the stems in various stands were accumulated rather than bunched singly. Spinelli et al (2007) studied two accumulating Timberjack heads – the TJ 720 and TJ 730, with cutting capacities of 20 and 30cm, respectively. They were 50% more productive than non-accumulating heads. When felling trees averaging 6.7 cm dbh, the TJ 720 averaged 2.6 trees per cycle. We have used this information to estimate that a multi-stem head would increase harvester productivity by 50% for 4” trees, 25% for 6” trees and not at all for 8” trees. With these assumptions, the cost savings would be $20/GT for the smallest trees and $5/GT for 6” trees.

Forwarder with Roll-On/Off Chassis

Deficiencies addressed: Multiple handling of small logs by the forwarder.

While roll-on/off trucks and containers have been used in numerous on-road applications and in off-road situations for chips, only recently have they been tested for use with log forwarders (Thomas 2008). The most time savings would occur if loaded log bunks were transferred from a forwarder to a transport truck, rather than offloading the logs from a conventional forwarder to the ground and then rehandling them again to load the truck. Even in the chipping scenarios we’ve posed, use of roll-on/off bunks would eliminate the unloading time by the forwarder. This scheme would be practical if chipping was rather close-coupled to forwarding, so the number of bunks required for the buffer between the forwarder and chipper could be kept to a reasonable value. The chassis and additional bunks would add some capital requirement and therefore increase hourly cost a bit, but this would be offset by increased productivity. We estimate the cost benefits to be approximately $1-2/GT.

Continuous-Travel Forwarder with Continuous-Feed Loading

Deficiencies addressed: Piece-handling nature of forwarder grapples; start-stop travel of forwarders while loading; need for the operator to continuously control the boom and grapple.

Logs produced by harvesters are generally windrowed in rather predictable rows alongside the forwarder trail, and they must be delivered to a known location – the log bunk. Agricultural hay-bale pickup machines have similar although somewhat simpler challenges and can travel continuously at reasonable speeds without requiring the operator to tediously pick up each bale. Although no continuous-feed loading device for logs exists at present, it should be relatively easy to automate this activity, compared to automating something such as selective felling. We simulated a continuous-feed machine by eliminating the loading times (while stopped; representative values are 10-15 minutes per cycle) from four empirical studies for which cycle times had been reported in considerable detail. We retained the observed travel while loading (on the order of 3 minutes per turn) and other elements. We also assumed such a machine would have an hourly cost that might be roughly a third more than a conventional forwarder. Based on these assumptions, we estimated a net benefit of $2/GT for larger trees to $5/GT for the smallest trees compared to a conventional forwarder.

Harwarder with Rotating Bunk

Deficiencies addressed: Multiple handling of small logs by the system.

In a conventional CTL system, each piece is handled at least three times before it reaches a truck: once by the harvester and twice by the forwarder (loading and unloading). Newer harwarders with processing/loading heads and rotating bunks can eliminate most of the loading activity by processing most logs directly into the bunks. Talbot et al. (2003) conducted a detailed simulation of two harvesters: a Valmet Combi that could process directly into a fixed bunk, and a Ponsse

Dual that operated first as a harvester, then as a forwarder. The Combi outproduced the Dual under all conditions. Asikainen (2004) reported that the productivities of either machine operating in single-function fashion were less than the equivalent single-function machine's productivities due to the impossibility of optimizing the multi-function machines for each activity. Without considering move-in, costs for the Combi and Dual were 15-20% and 10-15% higher, respectively, than those for a two-machine system. For the specific move-in assumptions stated in the study, the harwarders were less expensive than two-machine systems when less than approximately 30 m^3 (about 25GT) were removed from a harvest unit. Although not considered explicitly in these studies, Talbot et al. (2003) noted that either type of harwarder is at least superficially a self-balancing system in that the machine is busy until the unit is finished, while a two-machine system may require more hours by one than another, e.g. the harvester if small trees are being processed and forwarding distances are short. But the harwarder's hidden imbalance relates to successive activities rather than simultaneous: e.g., the harvester is idle while the machine is forwarding logs.

Wester and Eliasson (2003) tested a harwarder with a combination processing and loading head and a rotatable, tiltable bunk that allowed more logs to be processed directly into the bunks. The rotation capability increased productivity by 6% in clearfell and 20% in thinnings. There was less gain in clearcutting because in that case many of the logs could be processed directly into a fixed bunk. Not considering move-in, the harwarder with rotating bunk was about 20% and 35% more expensive in thinning and clearfell, respectively, than a two-machine system. Under the given move-in scenario, the systems broke even at 87 m^3 (about 25GT).

IV. Possibilities in General

A. Automation

Interest in automation of forestry tasks dates back at least 20 years (e.g., Courteau, 1990), and some advances have been successful, at least on an experimental basis. For example, Bonicelli et al. (1989, cited by Asplund and Fukuda, 1993) developed a thinning machine that used laser and ultrasonic sensors to find target trees and position the harvester head, even while the base machine was moving. Theilby and Have (2007) developed an autonomous weeder for Christmas tree plantations. It was competitive with weeding by hand and expected to soon match herbicide application in economic attractiveness.

Remote control is at the low end of the automation scale, yet it has some niche opportunities. For example, the Besten remote-controlled CTL harvester allows two forwarder operators to share the same harvester while eliminating the harvester operator. Under specific conditions of stand density and forwarding distance, this combination is less costly than a traditional combination of harvesters and forwarders or a harwarder (Bergkvist, 2006; Bergkvist et al., 2007). Remote control also has advantages in situations where an on-the-machine operator might be exposed to dangers such as rollover. In a non-forestry application, an ASV was remotely controlled to clear unexploded ordnance (ASV Inc., no date). A group in Idaho has developed a small remote-controlled vehicle – the Logg Dogg (Forest Robots LLC., 2006) – for forestry applications, although the advantages of this particular vehicle, other than the lower weight of an operatorless machine, are not apparent.

A second level of automation might be termed “smart” motion control, in contrast to manual control. This is particularly applicable to machines with multi-section booms. Under manual control, the operator manipulates a set of levers or joysticks, with each motion controlling one of several cylinders or motors to activate a particular joint on the boom or head. With “smart” control, the operator would simulate the desired motion, for example with an instrumented glove, and a computer would determine which valves to activate to obtain the desired result. Freedman et al. (1995) reported on the Canadian ATREF project involving universities, industry and FERIC to develop coordinated control of the end-effector on a multi-purpose prime mover. Guimier (1999) stated that work at that time focused on boom-tip control, where the operator points a lever in the desired direction and the computer determines how to get there. Lofgren (2007) simulated boom-tip control for CTL harvesters and forwarders and estimated a 30% improvement in productivity as well as a more rapid learning curve for new operators. The system would substitute a single knob for the conventional two joysticks.

True autonomous equipment is the holy grail, but some experts feel that fully autonomous forest robots are rather unlikely (Guimier, 1999). Halme and Vainio (1998) stated that the technologies for robotics and autonomous vehicles already exist and are being employed in industries such as mining because of the large scale and substantial resources. They felt it was harder to migrate these technologies into forestry because most logging firms are rather small. In addition, forests are rather undefined environments when compared to agricultural or on-road settings. Another issue is the high development cost for a limited market. If it does eventuate, the first autonomous equipment may be for primary transport on predetermined paths, using a combination of gyroscopic dead reckoning and GPS or radio beacons as feedback inputs. Considerable advances have been made in automated guidance of agricultural vehicles, and some efforts have been made to develop controllers for navigation in forests (Canning et al., 2004). Although the actual transport might be autonomous, loading and unloading might still be accomplished by humans (Asplund and Fukuda, 1993). Future automation is likely to allow operators to focus on “strategic decisions rather than on routine operating tasks” such as placing logs in piles, grabbing a tree for delimbing or traveling in a straight line (Guimier, 1999). The operator will concentrate on activities that are more difficult to automate because they require perception, assessment and/or planning (Halme and Vainio, 1998).

Robots have been employed in fixed-base agricultural operations since the early 1980s, e.g., there are robotic mushroom harvesters that work 24 hours per day, but applications in the field have only been tested in the last decade or so (Grift et al., 2006).

Although the price of automated technologies for difficult environments is currently high, it is dropping rapidly. Events such as the DARPA Grand Challenge and international Intelligent Ground Vehicles Competition are advancing the state of the art. While in the past, single robots were operated by teams of humans, we are moving to the day when multiple robots will operate under minimal human supervision (Bellingham and Rajan, 2007). Some experts are working on flockbots, i.e., robots that work together to carry out tasks (George Mason University, 2005).

Due to its piece-handling character, the felling of small trees in selective cutting is clearly the area that most needs the advantages of automation. At present, a human identifies each tree to be removed, then manually controls the machine to cut and bunch or process. In a semi-automated system, the operator would identify each tree to be cut, maybe by "painting" it with a laser, and the machine would take carry out the actual handling of the trees. A third level might involve multiple machines. In fact, Halme and Vainio (1998) expect the first semi-autonomous, multi-machine system to be used for cutting and processing, with one human making high-level decisions and several machines carrying out the work. The operator might "paint" only the leave trees, and a fleet of cutter-collectors would then identify and handle the stems to be removed.

It is of interest to note that the ATREF project did not result in a commercial boom-tip control, but instead generated two training simulators – one for harvester operators and a second for forwarder operators – that run on personal computers and are available as a set for $3500 from Simlog in Montreal, Quebec (Simlog, 2008). Training simulators are also available from equipment manufacturers.

B. Multi-Function Equipment

As Asikainen (2004) described, combining multiple functions into one machine has possible advantages and disadvantages. The former include:

- Lower capital cost than two separate machines
- Fewer operators than with separate equipment
- Opportunities to eliminate repeated handling by separate machines

Possible disadvantages include:

- More expensive per hour than any machine handling subsets of the multiple functions
- Lower move-in cost per area since fewer machines to move
- Equipment is more complex
- Reliability of a machine is the product of the reliabilities of the components; unless each element is robust, a multi-function machine is likely to be down a lot.
- Difficult to optimize for any of the functions
- Greater size and weight than each of multiple separate machines

For very small units, the move-in issue favors multi-function equipment. For example, let's assume a five-acre parcel with 25 GT/acre to be removed. If move-in costs $500 per machine and combining functions reduces the system by one machine, the move-in savings translates into a substantial $4/GT. But if the parcel has 50 acres and the transport expenses are only $250 per machine, the move-in differential is only $0.2/GT.

Ignoring move-in, multi-function machines are likely to be advantageous when all functions can work simultaneously, they are well-balanced in production potential, and the combined machine eliminates handling that would otherwise be necessary. A chain flail delimber-debarker-chipper is an example of a machine where the functions go on simultaneously and handling between physically separated equipment is eliminated. (Early chain flail delimber-debarkers paired with separate chippers required three pieces of equipment – a loader to feed the flail, the flail and the chipper – and two operators – one on the loader and another on the chipper.) Depending on season, tree size and species, the difficulty of bark removal and therefore the capacity of the flail may be more limiting than that of the chipper, but in general the two components are well balanced.

Older-style harwarders – those that operate strictly as a harvester and then change to forwarder mode – have no potential to produce at lower cost than a separate harvester and forwarder, each working at its own rate. Newer machines that process trees directly into the forwarding bunks make one handling serve two purposes (loading as well as processing) and may be less expensive than separate machines when forwarding distances are short (Bergkvist, 2007b).

A feller-chipper is another concept with potential because both functions can occur simultaneously. But the balance between these two functions is quite sensitive to tree size because felling rate is piece-limited while chipping productivity is mass-limited. Past experience in Finland found felling to be substantially less productive than chipping, but conditions in California, i.e. larger trees than in Finland going to biomass markets, might make the combined machine more attractive here.

C. System Balance Considerations

Balancing is an important issue for multi-machine systems. As noted above, we've ignored it in our cost calculations because, in practice, operators make adjustments to compensate for imbalances. We wish to comment on cases where underutilized equipment may not cause too much cost penalty. These are situations where a machine has low hourly cost due to low capital investment and no dedicated labor. For example, Bolding (2003), Bolding and Lanford (2005) and Westbrook et al. (2007) added relatively small chippers to operations to produce biomass chips. The chippers were idle much of the time, but because they were inexpensive and controlled remotely by operators of other equipment, the associated costs were not high.

V. Conclusions and Summary of Primary Recommended Improvements

We identified two major drawbacks for current harvest systems for small trees: the piece-handling characteristic of felling equipment, and the use of small, manually controlled grapples to move wood.

Develop automated felling and bunching equipment. A first step is boom-tip control. The next level might combine selection by the operator of trees to be removed with automated control of boom motion to cut and bunch. A higher level of sophistication would focus the operator's attention on selecting (the probably fewer) trees to be retained while automating the process of identifying and removing the rest. With either option, one operator might be able to "manage" two booms on a single machine, or multiple machines.

Develop a continuous-travel feller buncher. This would have considerable potential to reduce costs per ton, yet is one of the most challenging development projects due to the conditions of selective harvesting in naturally regenerated stands.
Develop a selective feller-grinder-forwarder. Many areas in California are too steep to be traversed by fixed-head masticators. Successfully adapting the concept of the NCSU/FECON masticator-collector to a boom-mounted masticator would be challenging but rewarding.

Replace human-operated booms and end-effectors (cutting heads or grapples) with other means of acquiring and transporting (over short distances that a boom normally travels) small trees. Applications include felling and bunching, harvesting, grappling unbunched trees with a skidder, loading and unloading logs onto/off of a forwarder, feeding a chipper, and picking up slash to load a bundler or slash forwarder. There are two general approaches to this: dumb swathing and smart targeting. Swathers such as scrapers for soil; front-end loaders for wood chips, sand and gravel; non-selective agricultural harvesters for row crops and forage; and harvesters for short-rotation trees all use the dumb approach: they acquire whatever is in within the machine's design swath width. Similar approaches seem feasible for activities such as picking up logs windrowed by a harvester along a trail, or collecting surface fuel from the path to be taken by the collector's prime mover. Swathing within a stand to either side of a travel path is more challenging, but a swathing head mounted on a human-operated boom might be able to acquire multiple trees or pieces without the operator having to address each one separately. A further step might involve using sensors or input from the operator to identify areas that are off-limits (because a leave tree or piece of down woody material is located there, for example), and then having the swathing head cover the rest of the area. The smart targeting approach would identify each object to be acquired and robotically move the head to it. The mechanical equipment in this case would probably look very similar to that controlled by the human now.

Develop a whole-tree forwarder for partial cuts. A whole-tree forwarder with an accordion or piggyback rear axle and bunk may have similar or better potential for selective harvest conditions than a skidder with a large grapple because the trees can be confined within the bunks. The accordion or piggyback feature would allow the machine to turn around easily with in selectively harvested stands.

Develop a semi-automated loading mechanism for CTL forwarders, to replace the boom and grapple (or at least the manual controls for such), allowing the forwarder to travel continuously.

References

Asikainen, A. 2004. Integration of work tasks and supply chains in wood harvesting - cost savings or complex solutions? Intl. J. Forest Eng. 15(2):11-17.

Asplund, C. and A. Fukuda. 1993. Future use of robotics in forestry. In: Proceedings IEEE/Tsukuba International Workshop on Advanced Robotics, 1993. 'Can Robots Contribute to Preventing Environmental Deterioration?' 103-107.

ASV Inc. Posi-Track helps clear Panama of unexploded ordinance items. Accessed 2008. http://www.asvi.com/pdfs/apps_stories/MD70_bd_panama.pdf.

Bellingham, J. G. and K. Rajan. 2007. Robotics in Remote and Hostile Environments. Science 318(5853):1098-1102.

Bergkvist, I. 2003. Multitree-handling increases productivity in smallwood thinning. Skogforsk Results No. 3.

Bergkvist, I. 2006. The Beast - a technological breakthrough. Skogforsk News No. 3.

Bergkvist, I. 2007. Harwarders in final felling. Resultat Nr. 15. Skogforsk.

Bergkvist, I., B. Norden and H. Lundstrom. 2007. The Beast, a remote controlled harvester. In: Sustainable Forest Operations - The Future is Now! 3rd Forest Engineering Conference, COFE 30th Annual Meeting. Mont-Tremblant, Quebec, Canada: COFE.

Biologistiikka Oy. 2005. Valmet 801 Combi BioEnergy. Accessed 2008. http://www.biologistiikka.fi/valmet_801_combi_bioenergy.html.

Bolding, M. C. 2003. Forest fuel reduction and energywood production using a CTL/small chipper harvesting system. Auburn, AL. Auburn University. M.S. Thesis.

Bolding, M. C. and B. L. Lanford. 2005. Wildfire fuel harvesting and resultant biomass utilization using a cut-to-length/small chipper system. Forest Prod. J. 55(12):181-189.

Bonicelli, B., L. Lucas, F. Perret and J. C. Bonnafous. 1989. Robot arm for forest thinning R.A.F.T. ASAE Paper No. 89-7056. 1989 International Summer Meeting. 9 p. Quebec City, Quebec: ASAE.

Brinker, R. W. and R. A. Tufts. 1990. Economics of a cut-to-length harvesting system in second thinnings. In: Proceedings of Managing Forestry Operations in a Changing Environment. 13th COFE Annual Meeting. 84-88. Outer Banks, NC: COFE.

Canning, J. R., D. B. Edwards and M. J. Anderson. 2004. Development of a fuzzy logic controller for autonomous forest path navigation. Trans. of ASAE 47(1):301-310.

Courteau, J. 1990. Robotics in forestry: an industry response. Special Report SR-75. Vaudreuil, Quebec: Forest Engineering Res. Inst. of Canada.

Dempster, P., N. Gallo, B. Hartsough, B. Jenkins and P. Tittmann. 2008. Sponsorship-Equipment Review, Agreement Number 8CA05704, Final Report to State of California Department of Forestry and Fire Protection. Department of Biological and Agricultural Engineering, University of California, Davis. 26 December. http://biomass.ucdavis.edu/CDFEquipmentReviewFinalRept26aDec08.pdf

Fight, R. D., B. R. Hartsough and P. Noordijk. 2006. Users guide for FRCS: fuel reduction cost simulator software. Gen. Tech. Rep. PNW-GTR-668. Portland, OR: USDA, Forest Service, Pacific Northwest Research Station.

Forest Robots LLC. 2006. The Logg Dogg. Accessed September 7, 2008. http://www.forestrobots.com/Logg_Dogg/index.html.

Freedman, P., E. Papadopoulos, D. Poussart, C. Gosselin and J. Courteau. 1995. ATREF: Application of Robotic Technologies to Forestry Equipment. In: IEEE Canadian Conference on Electrical and Computer Engineering. 1140-1143. Montreal, Quebec.

George Mason University- Department of Computer Science CS-499 Spring 2005. 2005. Flockbots. Accessed February 2008. http://cs.gmu.edu/~eclab/projects/robots/flockbots/pmwiki.php?n=Main.Home.

Gingras, J. F. 2004. Early studies of multi-tree handling in eastern Canada. Intl. J. Forest Eng. 15(2):18-22.

Grift, T. E., M. Kasten and Y. Nagasaka. 2006. Development of autonomous robots for agricultural applications. 10 p. Urbana-Champaign, IL: University of Illinois.

Guimier, D. Y. 1999. Canadian forestry operations in the next century. Intl. J. Forest Eng. 10(1):7-12.

Halme, A. and M. Vainio. 1998. Forestry robotics - why, what and when. Lecture Notes Control Information Sci. (236):151-162.

Hartsough, B. and R. Spinelli. 2002. Productivities and costs of short-rotation woody crops harvesting technologies: projections for American plantations. Final Report to Oak Ridge National Laboratory. University of California, Davis. 53 pages.

Johnson, L. R. 1989. Wood residue recovery, collection and processing. Supplement to the Biomass Energy Project Development Guidebook. Moscow, Idaho: Forest Products Dept., University of Idaho.

Kärhä, K., A. Jouhiaho, A. Mutikainen and S. Mattila. 2005. Mechanized energy wood harvesting from early thinnings. Intl. J. Forest Eng. 16(1):15-25.

Lilleberg, R. 1990. Kuormainharvesteri avo-ja harvennushakkuissa. Maksuperustetutkimus. [Boom-mounted harvester in final cuttings and thinnings. Cost base study]. Monisteita 28.3. Metsäteho.

Lofgren, B. 2007. Automation and human machine interaction improvements of forest machines. In: Sustainable Forest Operations - The Future is Now! 3rd Forest Engineering Conference, COFE 30th Annual Meeting Mont-Tremblant, Quebec, Canada: COFE.

Logset. Accessed 2008. www.logset.com/tmp_logset_site_8.asp?lang=3&sua=1&s=135.

Mitchell, C. P., L. B. Hudson, D. N. A. Gardner and P. G. Storry. 1989. Systems for harvesting wood for energy in the UK. In: Harvesting Small Trees and Forest Residues. Proceedings from an International Symposium. B. J. Stokes ed. 51-56. Auburn, AL USDA, Forest Service, Southern Forest Experiment Station, Auburn, AL.

Molbak, I. and P. Kofman. 1991. Scandinavian chipping techniques - computer database. Final Report. International Energy Agency- Bioenergy Agreement, Task VI, Activity 3. U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, Auburn, AL.

Parker, R. 1999. Japanese long-boom feller-buncher. LIRO Newsletter 24(6):2.

Pentin Paja Oy. Accumulating Narva-Grip 1600-40. Accessed 2008. pentinpaja.fi/main.site?action=app/prodinfo/view_product&id=&pid=33.

Pottie, M. A. and D. Y. Guimer. 1986. Harvesting and transport of logging and residuals and residues. FERIC Special Report No. SR-33. Pointe Claire, Quebec: Forest Engineering Res. Inst. of Canada.

Roise, J.P., L.C. Hannum and G.P. Catts. 2009. Machine System for Harvesting Small Diameter Woody Biomass and Reducing Hazardous Fuels: A Developmental Report. ASABE Paper Bio090001. 2009 Bioenergy Engineering Conference, Seattle, Washington. October 11-14.

Silvatec. 2005. Silvatec 878 CH. Accessed 2008. http://www.silvatec.com/media/silvatec_878_chipper.pdf.

Simlog. 2008. Harvester personal simulator. Accessed 2008. www.simlog.com/personal-harvester.html.

Siuro, A. 2007. Not just efficient - eco-efficient. Accessed 2008. www.hightechfinland.fi/direct.aspx?area=htf&prm1=586&prm2=article.

Spinelli, R., E. Cuchet and P. Roux. 2007. A new feller-buncher for harvesting energy wood: Results from a European test programme. Biomass and Bioenergy 31(4):205-210.

Spinelli, R. and B. Hartsough. 2001. A survey of Italian chipping operations. Biomass and Bioenergy 21(6):433-444.

Suadicani, K. 1989. Harvesting small trees in Denmark. In: IEA/BE, Task IV, Activity 3, Proceedings of an international symposium. Harvesting Small Trees and Forest Residue. B.J. Stokes ed. Auburn University, AL.

Talbot, B., T. Nordfjell and K. Suadicani. 2003. Assessing the utility of two integrated harvester-forwarder machine concepts through stand-level simulation. Intl. J. Forest Eng. 14(2):31-44.

Theilby, F. and H. Have. 2007. Autonomous weeder for Christmas tree plantations. Forest and Landscape. University of Copenhagen. Poster presented at Sustainable Forest Operations - The Future is Now! 3rd Forest Engineering Conference, COFE 30th Annual Meeting. Mont-Tremblant, Quebec: COFE.

Thomas, C. 2008. Personal communication with Bruce Hartsough. Cky-Ber Enterprises, Stevensville, MT.

Twaddle, A. A., B. J. Stokes and W. F. Watson. 1989. Harvesting small stems and residues for biofuels: an international perspective. ASAE paper No. 897545. 1989 International Winter Meeting of the American Society of Agricultural Engineers. New Orleans, LA.

Ulich, W. L. 1983. Development of a biomass combine. Report No T-3-103. Lubbock, TX: College of Agricultural Sciences, Texas Tech University.

Westbrook, M. D., W. D. Greene and R. L. Izlar. 2007. Utilizing Forest Biomass by Adding a Small Chipper to a Tree-Length Southern Pine Harvesting Operation. Southern J. Applied Forestry 31:165-169.

Wester, F. and L. Eliasson. 2003. Productivity in Final Felling and Thinning for a Combined Harvester-Forwarder (Harwarder). Intl. J. of Forest Eng. 14(2):45-52.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

ENERGY CONSUMPTION OF SMALL SCALE PRODUCTION SYSTEMS FOR FUEL WOOD CHIPS

by

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ABSTRACT: The purpose of this study was to clarify the energy efficiency of the production system for fuel wood chips as an alternative energy to fossil fuel and to clarify where comminuting operation must be carried from a point of view of energy consumption. For these purposes, fuel consumption of felling, extraction, transportation and comminuting processes were measured and energy consumption ratio was calculated. Our investigation showed that the energy consumption ratio for comminuting process was much larger than felling, extraction and processing processes when the mobile chippers were used, while the energy consumption of the stationary chipper was at the same level as that of other processes. The energy consumption ratio for the mobile chipper for primary chipping was small because of their large screen size, and this resulted in a lower energy consumption ratio of two path comminuting process than one path comminuting process. The total energy consumption ratio for the two path comminuting system was smaller than that for one path comminuting system when the transporting distance was long. The turning distances varied depending on trucks; however, the energy consumption ratio at the turning distances remained unchanged.

KEYWORDS – Energy consumption ratio, fuel consumption, comminuting process, transporting process, mobile chipper, screen size.

INTRODUCTION

The most usable form of forest biomass in Japan is logging residue from final cutting because it can be easily collected from landings around forest roads. Logging residue is, however, decreasing as the area of final cutting is decreasing due to low log prices from economic slump. At the same time, non-commercial thinning is carried out in many stands with subsidies although the tree sizes are large enough for commercial use. As a result, much wood biomass is left in thinned stands while it has a high potential as a replacement for fossil fuel. It must be used as fuel more and more because it has advantage of carbon neutral.

The purpose of this study was to clarify the energy efficiency of the production system for fuel wood chips as an alternative energy to fossil fuel and to clarify where comminuting operation must be carried from a point of view of energy consumption. For these purposes, fuel consumption of felling, extraction, transportation and comminuting processes were measured and energy consumption ratio was analyzed. Thinning operations on strip roads which form high density road networks were examined. Thinned trees were extracted with grapple loaders and processed into short logs with chain saws, and then the logs were carried to landings with two-ton dump trucks. A part of the logs were directly loaded on trucks and the others were comminuted with a mobile chipper and filled into containers.

The logs and chips were transported to a sawmill and comminuted into fuel chips with a mobile chipper or a stationary chipper.

STUDY SITES

This study was conducted in Kofu city and Fuefuki city of Yamanashi prefecture which is on the west side of Tokyo and in the central part of Japan. These sites have a characteristic where their landings are on the sites a few kilometers from cutting sites. The dominant tree species at the former site is Japanese cedar (*Criptmeria japonica*) while the latter is mostly Japanese cypress (*Chamaecyparis obtusa*) and Japanese larch (*Larix kaempferi*). Their stand ages are 40 and 35 years, stand areas are 2.27 and 3.18 ha, and distance between cutting site and landings are about 3.4 and 4.8 km respectively (Table 1). Felling operation is done with chain-saws, delimbing and bucking operation is carried with chain-saws in Kofu city and a harvester in Fuefuki city, and extracting operation is carried mainly with grapple loaders and sometimes with a winch equipped the grapple loader. These operations are done at the cutting site and the logs are carried to landings with two-ton dump trucks. At landings, a part of logs are loaded on other trucks which are four-ton arm roll trucks, four-ton trucks, ten-ton dump trucks and ten-ton trucks, and the others are roughly comminuted with a mobile chipper using 150 mm screen, filled into containers and carried with arm roll trucks. The trucks transport logs and chips to a sawmill. At the sawmill, the chips are comminuted into fuel chips with a mobile chipper and the logs are comminuted into fuel chips with a mobile chipper or a stationary chipper. The specifications of the machines are shown in Table 2.

Table 1. Specifications of study sites

Place	**Tree species**	**Stand age (years)**	**Area (ha)**	**Tree density (ha^{-1})**	**Distance between cutting site and landings (km)**	**Distance between landings and saw mill (km)**
Obina, Kofu city	Japanese Cedar	40	2.27	1200	3.1, 3.2, 3.6	27.9
Kamikurokoma, Fuefuki city	Japanese Cypress and Japanese Larch	35	3.18	1200	4.8	19

Table 2. Specifications of used machines

Machine	Model	Fuel	Mass (kg)	Output (exhaust volume) / bucket volume
Grapple loader	HITACHI EX-30	Diesel	2,770	0.08 m^3
Grapple loader	HITACHI EX-120	Diesel	9,300	0.45 m^3
Grapple loader	KOMATSU PC35-MR-3	Diesel	2,910	0.09 m^3
Harvester	HITACHI ZX 75Us	Diesel	5,800	40.5kW
Chain saw	ZENOAH G3700	Gasoline	4	37.2 cc
Mobile chipper	MOROOKA MC2000	Diesel	11,600	145 kW
Mobile chipper	RYOKUSAN ROTO300F	Diesel	15,876	261 kW

METHODS

In this analysis, energy consumption was measured as fuel consumption or electric power consumption. Fuel consumption was measured as the mass of fuel filled into each machine. The electric power consumption of a stationary chipper was calculated from bills. The mass of logs transported between landings and the sawmill were measured with a truck scale at the sawmill. The bulk ratio of logs was calculated from their mass divided by the interior content of a container on an arm roll truck. The distances between the cutting sites and the landings and between the landings and the sawmill were measured with trip meters of each truck.
Fuel consumption ratio of others than trucks is calculated with linear regression method between the mass of logs and fuel consumption. Here, the coefficient of regression shows the fuel consumption ratio. Fuel consumption ratio of trucks is calculated as fuel mass or volume per load per distance. Fuel consumption ratio of some trucks is calculated with load-distance method because their fuel consumption could not be measured directly. Fuel consumption ratio is calculated with formula (1) in load-distance method.

$$\ln \quad = 2.71 - 0.812 \ln \quad - 0.654 \ln m_0 \quad (1)$$

Here, : fuel consumption ratio (L/t km), : loading ratio, m_0 : maximum load (t).
Energy consumption ratio is calculated from the fuel consumption ratio multiplied by a conversion factor.

RESULTS AND DISCUSSIONS

The calculated energy consumption ratio for each operation is shown in Table 3. In the extraction operation, the use of winch makes energy consumption ratio larger and energy consumption ratio of slashes is larger than that of logs. For the processing operation, energy consumption ratio of a harvester was more than ten times larger than a chain saw. In the chipping operation, energy consumption ratio of the mobile chipper for primary chipping was relatively small because of its large screen size and the total energy consumption ratio of primary and secondary chipping operation was smaller than that of final chipping operation without primary chipping. The energy consumption ratio of stationary chipper is much smaller than mobile chippers. In the loading operation, the energy consumption ratio of loading logs on a truck was much smaller than other operations.

Energy consumption ratio of each process is calculated from the results above, and the results are shown in figure 1. The energy consumption ratio of felling, processing and extracting processes are much smaller than that of comminuting processes. The figure shows that the energy consumption ratio of two path comminuting is smaller than that of one path comminuting. This means that the primary chipping process at landings, transporting as chips and final chipping at sawmill has an advantage from the point of view of energy consumption ratio. This is due to the fact that the energy consumption ratio of the mobile chipper for primary chipping is small and the energy consumption of the mobile chipper used at the sawmill becomes much smaller in secondary chipping.

The weight of payloads on fully loaded trucks depends on the form of their contents. The maximum payloads of a fully loaded four-ton arm roll truck are 1.4 tons with logs, 2.1 tons with chips and 0.5 tons with slashes. These weight differences results in a variety of energy consumption ratios for transporting process. Figure 2 shows the relationships between the transporting distances and their corresponding energy consumption ratios. Here, the energy consumption ratio of one path comminuting process is smaller than two path comminuting process when the transporting distance is short, while that of two path comminuting process is smaller than one path comminuting process for longer transporting distances. The intersection point is about 9 kilometers of transporting distance and the energy consumption ratio is approximately 300 MJ/t. Here, assuming that the variance ratio of the maximum payloads according to their forms for a ten-ton dump truck is the same as a four-ton arm roll truck, the corresponding distance will be about 22 kilometers while the energy consumption ratio remains constant at about 300 MJ/t.

Table 3. Energy consumption ratio of each operation

Operation	Energy consumption ratio (MJ/t)
Extraction of logs with a grapple loader	40.70
Extraction of logs with a winch	70.04
Extraction of slashes with a grapple loader	87.56
Processing with a chain saw	5.89
Processing with a harvester	77.75
Primary chipping with a mobile chipper	83.33
Final chipping with primary chipping by a mobile chipper	128.32
Final chipping without primary chipping by a mobile chipper	256.21
Final chipping without primary chipping by a stationary chipper	82.35
Loading logs on a truck with a grapple loader	15.20
Loading slashes on a truck with a grapple loader	64.86
Putting logs into a mobile chipper with a grapple loader	66.55
Sorting logs and slashes at sawmill yard with a grapple loader	19.11
Carrying logs and slashes at sawmill yard with a fork lift	7.79

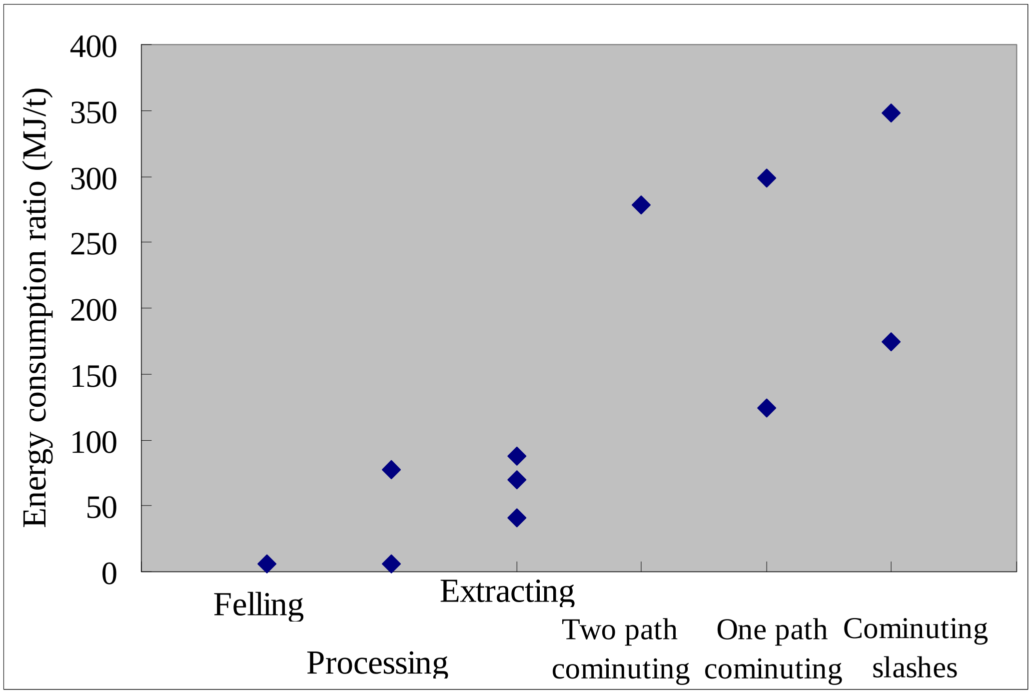

Figure 1. Energy consumption ratios of each process

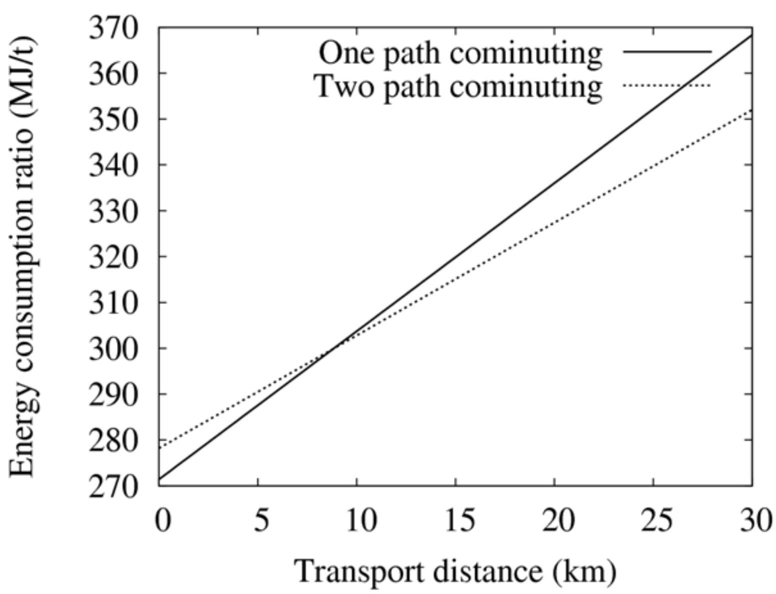

Figure 2. Energy consumption ratios for various transporting distances

CONCLUSIONS

Fuel consumption of felling, extracting, processing, comminuting and transporting processes was measured and energy consumption ratio was calculated. Our investigation revealed that the energy consumption ratio of comminuting process was much larger than felling, extracting and processing processes when the mobile chippers were used, while the energy consumption of the stationary chipper was at the same level as that of other processes. The energy consumption ratio of the mobile chipper for primary chipping was small because of their large screen sizes. This resulted in a lower energy consumption ratio for two path comminuting process than one path comminuting process. Yoshioka et. al. (2006) reported that there was no significant difference in fuel consumption between comminuting at landings and at a mill, which contradicts our finding. This difference means that fuel consumption varies depending on conditions and indicates that there must be an optimum condition for reducing energy consumption.

The energy consumption ratio of chip transporting process is smaller than that of log transporting process because of their large bulk ratio. This caused the total energy consumption ratio of two path comminuting system to be smaller than that of one path comminuting system when the transporting distance was longer than 9 kilometers. Assuming that the variance ratio of the maximum payload of a ten-ton dump truck was the same as a four-ton arm roll truck, the turning distance could be extended by 22 kilometers. It is interesting to note that the energy consumption ratio at the turning distances remained constant at about 300 MJ/t for both the four-ton arm roll truck and the ten-ton dump truck.

REFERENCES CITED

Yoshioka, T., Aruga, K., Nitami, T., Sakai, H., and Kobayashi, H. (2006) A case study on the costs and the fuel consumption of harvesting, transporting, and chipping chains for logging residues in Japan. Biomass and Bioenergy, 30: 342 - 348

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COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Harvesting Understory Biomass with a Baler

by

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Abstract: A model WB-55 Biobaler[1] was evaluated while operating in a pine plantation to remove understory biomass. The harvested material was formed into round bales which averaged 1004 lbs. Mean heat content was approximately 8560 Btu/lb oven-dry. Time-study data revealed a productivity of 14.7 bales/PMH with a mean travel distance of 752 feet between bales. In-woods cost was between \$17 to \$18/gt (green ton). Size classification of unprocessed baled material and material processed thru a chipper and a haybuster resulted in an increase in the 4.75 mm size class from 29 percent of total weight to over 45 percent for both the chipper and haybuster. The intended purpose for baling understory biomass is to utilize the material as an alternative fuel source.

INTRODUCTION

Recent rises in oil prices have prompted new innovations in developing alternative fuel sources. Significant progress has been made in converting wood to bio-oil and bio-diesel. Transforming woody biomass into pellets for use as a fuel source is being accomplished by Green Circle, a company in Florida. Range Fuels, a Colorado company, focuses on producing low carbon biofuels and clean renewable energy using material such as harvesting residues, sawdust, corn stover, and switchgrass. Recognizing the potential these resources possess as a fuel source has resulted in the development of new technologies to harvest some of them.

One method of harvesting forest residues and biomass is with a round-bale hay baler. Baling of forest residues left from harvesting operations has some advantages when compared to chipping the material. Baling offers a means of compacting a loose or bulky material into unitized packages which can be easily handled. In addition, harvesting forest biomass using large round bales has the potential for having low energy costs compared to other harvesting and handling schemes, such as chipping (Fridley and Burkhardt, 1984). The concept of baling forest residues is not a new one. Fridley and Burkhardt (1984) evaluated a modified Vermeer 605F round-bale hay baler operating on a landing while baling prickly-ash, a hardwood/conifer mix, and red pine. Bale densities obtained ranged from 8.8 lb/ft^3 to 21 lb/ft^3. Stokes and others evaluated a Claas Rollant 62 round hay baler to bale small-diameter crushed trees. Oven-dry density was 113.7 kg/m3 with a moisture content of 38 percent green weight basis.

Other advantages to baling residues relate to storage and heat value. The increased density decreases storage area requirements. In addition, bales could be left in the field to dry. By hauling a product which is lower in water content, each legal limit load would transport a larger amount of energy (Schiess and Yonaka, 1983). Furthermore, baling is not rigidly linked to the

[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement of any product or service by the U.S. Department of Agriculture or other organizations represented here.

transport phase as with chipping, which would increase machine utilization (Schiess and Yonaka, 1983).

A more recent innovation in baling technology for forestry applications includes using a round baler to harvest standing understory biomass. This method has the potential to be a very effective tool for treating stands with an overly dense understory which would be hazardous to treat with fire. Similarly, areas near a WUI or adjacent to an Interstate where burning would be too risky would benefit from understory harvesting. The removal of the excessive fuel loading would reduce the risk of catastrophic wildfire, facilitate the reintroduction of prescribed fire, and improve wildlife habitat (Canto et.al., 2008). Two baling systems were evaluated while operating in three different stand conditions on the Osceola NF. One system incorporated a mulch-and-bale technique. Standing understory biomass was mulched using a Supertrak SK-140 and then baled using an off-the-shelf Claas Rollant 250 powered by a CAT Challenger MT545B tractor. The second system was a modified New Holland BR740 (Bio-baler) and was also powered by a CAT Challenger MT545B tractor. The baler was equipped with a cutter-head which enabled it to cut, shred, and bale material in one pass. Canto and Rummer (2008) reported production rates of 2.6 gt/PMH for the Bio-baler and 5.5 gt/PMH for the Claas. Bale density averaged 20 lb/ft^3 for the Bio-baler and 23 lb/ft^3 for the Claas.

Another baler designed to harvest understory biomass has recently entered the market. The FLD WB-55 Bio-baler, produced by the Anderson Group, is capable of cutting and baling material up to 5 inches in diameter. This paper reports the performance and cost of the baler along with bale characteristics which include weight, density, moisture content, heat value, ash content, and size classification.

METHODS

Equipment

The FLD WB-55 baler contained a 48-tooth rotor with a 7.5-ft cutting width and was mounted on Carlisle Trac Chief 14-17.5 NHS tires. Power to the baler was provided thru PTO by a Fendt 818 tractor. The Fendt 818 was mounted on Nokia 16.9-28 TR tires on the front and Nokia 20.8-38 tires on the rear. Minimum power requirement to operate the baler was 180 PTO hp. Power from the tractor PTO to the baler was split using a gear box which distributed power to two drive shafts. One shaft powered the mulching head while the other shaft powered the baler and rotofeeder. The chamber had a 4-ft x 4-ft capacity with chain driven tailgate rollers.

Stand Descriptions

The FLD WB-55 was observed in March 2009 while operating in a 28-year old loblolly pine (Pinus taeda) plantation which had been thinned using a fifth-row removal in 2007. The site was located approximately 20 miles east of Valdosta, GA in Echols County on land owned by The Langdale Company, a forest products company located in Valdosta, GA. Terrain was flat with a Mascotte soil series. The Mascotte series consists of poorly drained soils with a fine sand making up the A horizon (NRCS, 2009). A previous trial on the baler took place in October

2008 in a similar stand a few miles from where the March 2009 trial was conducted. However, this paper mainly focuses on data from the March 2009 trial.

Understory Biomass

Assessment of understory biomass loading was accomplished by installing 1 m^2 plots. Plot areas were measured and corners were marked with pin flags. All biomass inside the plot boundary was cut and placed in a large plastic bag. Material standing inside the plot but extended outside the plot boundary was severed at the plot's vertical plane and only the portion within the boundary was retained. In contrast, material that originated outside the plot but extended inside the plot boundary was also severed at the vertical plane and the portion which fell within the boundary was retained. Bagged material was weighed using a Pelouze hanging scale.

Baling

The baler traversed the stand traveling between rows. Two passes were made down thinned corridors while one pass was made down un-thinned corridors. Productivity was measured using time-and-motion. Elements evaluated included travel, turn, and wrap/bale. Any delays encountered were also noted and recorded. Travel time began when forward motion started and ended when forward motion stopped. Turn time included the time required to travel from the end of a row to the beginning of another row. The element began when the baler reached the end of a row and ended when the baler entered the next row. The wrap/drop element included wrapping the bale with twine and dropping it from the chamber. The element began when forward motion ceased and ended after a bale was dropped and forward motion resumed (Klepac and Rummer, 2009). Distance traveled while making a bale was measured using a rolo-wheel.

Extraction

A John Deere 541 farm tractor utilizing a spike on the front was used to transport bales from the woods to a landing. The tractor could carry only one bale per trip, which made production very low for this method. Since these were only test bales and it was not critical to transport them to a processing facility, this was the best available method for extraction.

Other equipment for bale extraction such as forwarders and small in-woods log trailers are being considered for future studies so that extraction production and cost estimates can be made for a high production setting where transport of bales to a feedstock processing facility in a timely manner is critical. An Anderson R-Flex 612 HD log trailer with a M-160 boom was made available for a few days of operation in June 2009 on Langdale property.

Processing

Bales can be processed in-woods at a landing or at the mill or facility where they will be used, depending on the type of feedstock required. Some options for processing include tub grinders, chippers, and horizontal grinders.

Test bales from the October 2008 trial were transported to Langdale's mill and processed in a tub grinder for use as boiler fuel. In addition, 100 bales from the October 2008 trial were transported to Herty Advanced Materials Development Center in Savannah, Georgia for testing. There, sixty randomly selected bales, 3 groups of 20 bales each, were processed with a Peterson horizontal grinder. Grates used in the grinder for repetitions 1 and 2 were 2,2,4,4 and 4,4,4,4, for the third repetition. From each repetition, three 55-gallon fiber drums were filled with the ground material for analysis of bulk density, moisture content, and size distribution. One drum from each repetition was ground with a Meadows hammer mill which had a 3/16-inch outlet screen. This material was analyzed for heat value and ash content.

Sample bales from the March 2009 trial were analyzed for moisture, heat, and ash content. A Woodsman horizontal drum chipper and a haybuster were both evaluated for in-woods processing of bales during June 2009. The number of bales required to fill a chip van was tallied for each machine and vans were weighed to determine payload. Also, samples were collected from each machine for moisture, heat, and ash content in addition to size classification. For size classification, dried material was processed thru 31.75 mm, 19 mm, 4.75 mm, 4 mm, 2 mm, and 0.84 mm screens. Material retained in each screen was weighed, along with material which passed thru the 0.84 mm screen and percent in each size class was calculated.

Bale Measurements

Weights of bales from the production study were weighed within 24 hours using a Dillon dynamometer. Bale width, horizontal diameter, and vertical diameter were measured to the nearest tenths of feet for estimating density.

Material was collected from a sub-sample of timed bales for moisture content and heat value determination. Samples were placed in plastic bags, sealed, and labeled. In the lab, they were weighed wet, placed in drying pans and dried in an oven at 105°C until a constant weight was obtained. Dried samples were then bagged and taken to the Biosystems Engineering Department at Auburn University for heat value and ash content analysis. There samples were processed thru a hammermill and then burned in a calorimeter for heat content determination.

RESULTS

Understory Biomass

Large amounts of woody biomass were prevalent throughout the understory. Species encountered consisted predominately of gallberry (*Ilex glabra L.*), with small components of waxmyrtle (*Morella cerifera L.*), blueberry (*Vaccinium elliottii*), saw palmetto (*Serenoa repens Bartr.*), sweetbay (*Magnolia virginiana L.*), eastern baccharis (*Baccharis halimifolia L.*), fetterbush lyonia (*Lyonia lucida Lam.*) and red maple (*Acer rubrum L.*).

Plot inventory data for the baler were expanded to reflect green tons per acre and are summarized in Table 1. Understory loading ranged from 4 gt/ac to 30 gt/ac, and averaged 11.29 gt/ac.

Table 1. Summary of understory woody biomass loading.

		Green tons/acre			
Machine	***N***	***Mean***	***SD***	***Min***	***Max***
Gallberry and other[1]	24	10.29	4.042	3.8	19.4
Red maple	24	0.25	1.229	0.0	6.0
Pine	24	0.75	3.495	0.0	17.2
Total	24	11.29	5.491	3.8	29.9

[1]Includes waxmyrtle, blueberry, saw palmetto, sweetbay, eastern baccharis and fetterbush lyonia.

Baling

Twenty-six observations of making bales were recorded for the FLD WB-55. Total cycle time averaged 4.3 minutes with a mean travel distance between bales of 752 feet and a production rate of 14.7 bales/hr. Combining bale weight and total time resulted in a productivity of 7.3 gt/PMH. Using the swath cutting width of 7.5 feet and combining it with total cycle time resulted in a mean of 2 ac/PMH.

Recovery efficiency was estimated using the ratio of baled tons per acre and mean biomass loading per acre. Data collected on the FLD WB-55 suggest a recovery efficiency of approximately 34 percent.

Table 2. Summary of elemental time study data for the FLD WB-55.

Variable	***N***	***Mean***	***SD***	***Min***	***Max***
Travel (min)	26	3.4	0.86	2.1	5.6
Turn (min)	26	0.4	0.38	0.0	1.6
Wrap/drop (min)	26	0.5	0.14	0.2	0.9
Total time (min)	26	4.3	1.01	2.7	6.7
Travel dist. (ft)	26	752.0	136.38	508	975
Turn dist. (ft)	26	41.7	35.62	0.0	95.0
Trv. speed (mph)	26	2.6	0.51	1.6	3.5
Bales/hr	26	14.7	3.15	9.0	22.1
Swath acres/hr	26	2.0	0.55	0.098	3.14
Recovery (%)	26	33.8	6.47	25.0	48.7

Extraction

Data was not collected on the John Deere 541 farm tractor for estimating productivity and cost to transport bales from the woods to a landing, since that would not be a typical method of operation. However, two options to consider would be to either use a small log trailer or a full size forwarder.

A small log trailer would be one option for moving bales from the woods. This system would have a lower production rate and would incur costs for two additional pieces of equipment; the log trailer and a tractor for pulling the trailer. During June 2009 a Anderson R-Flex 612 HD log trailer with a M-160 boom (Figure 4) was on site for two days. The trailer had a hauling capacity of eight bales and was rated at 1100 lbs maximum lift capacity at full extension.

Another option would be to use a forwarder. Either a small 4-wheel machine or a medium size 6-wheel machine could be considered, depending on the size of the operation. This option would incur more capital cost, however, productivity would be enhanced.

Processing

At the landing bales can be loaded directly onto flatbed trailers for transport, or processed into a desirable size using a tub grinder, a chipper, a horizontal grinder, or a haybuster. During June 2009 processing bales at the landing was tested with a Woodsman model 334 chipper and also with a model H-1100 Haybuster tub grinder.

The Woodsman chipper was a 440 hp machine equipped with an in-feed conveyer and a 36-inch wide drum. The throat opening measured 22-inch high x 36-inch wide. A CAT 559B knuckleboom loader was used to feed the chipper. A total of thirty bales were required to fill a chip van which resulted in a payload of 13.42 tons. It was determined that the chipper is not the most feasible machine to use for this process. The throat size was a limiting factor which required bales to be broken up before they could be feed into the chipper. At the throat entrance, material tended to bridge, which slowed production.

Figure 1. Processing bales with a Woodsman 334 horizontal drum chipper.

A Model H-1100 tilt series II Haybuster tub grinder was also evaluated for processing bales. The tub grinder is powered by PTO and requires 150 hp minimum for operation. In a production operation, this would require an additional tractor on site to provide power to the grinder. Processed material was transferred from the tub to an inclined conveyor for top loading a chip van. This resulted in higher utilization of the chip van with a payload of 19.07 tons. Using 3-inch and 4-inch screens the Haybuster processed 40 bales per hour. Increasing screen size to 5-inch and 6-inch screens increased production to around 60 bales per hour. The 559B knuckleboom loader was used only because it was readily available. A smaller, less expensive loader would be capable of performing the feeding operation at a lower cost.

Processing of baled material into smaller sizes may be desirable by the facility using the material. Size classification of unprocessed baled material, material processed thru the chipper, and material processed thru the haybuster is displayed in Figure 2.

The amount of fine material (<0.84 mm) was similar for unprocessed bales and chipped material (11.46 and 10.61 percent of total weight, respectively), with the highest amount (19.81 percent) associated with material processed with the haybuster. Material retained in the 0.84 mm screen was lowest for bales (5.07 percent), followed by the chipper (7.22 percent), and then the haybuster (10.60 percent).
Material retained in the 2 mm size class ranged from 6.98 for the haybuster to 11.73 percent for the chipper. Unprocessed baled material averaged 8.78 percent for this size class.

For the 4 mm size class, material retained ranged from 4.62 for bales to 8.26 percent for the haybuster. Chipped material averaged 5.15 percent for this size class.

The highest percentages occurred in the 4.75 mm size class for all three material types. In addition, processing material thru a chipper or haybuster resulted in the largest increase in this size class as compared to unprocessed material. Unprocessed material averaged 28.97 percent, compared to 45.69 percent for the chipper and 45.55 percent for the haybuster.

Processing material significantly reduced percentages in the 19 mm and 31.75 mm size classes for both the chipper and haybuster, as compared to unprocessed bales. The haybuster produced the least amount of 19 mm material (4.67 percent), followed by the chipper (7.47 percent) and unprocessed bales (13.44 percent). This same trend also occurred for the 31.75 mm size class with the haybuster containing the least amount (4.13 percent), followed by the chipper (12.12 percent) and unprocessed bales (27.67 percent).

Results from samples collected from unprocessed baled material, the chipper, and the haybuster are shown in Table 3.

Table 3. Results from unprocessed and processed material.

		Mean		
Variable	***N***	***Bales***	***Chipper***	***Haybuster***
Moisture content (% wet-basis)	3	35.7	42.1	42.9
Oven-dry heat of combustion (Btu/lb)	3	8660	8689	8640
Ash content (%)	3	1.8	1.5	5.0

Testing of a 200 hp Doppstadt horizontal grinder is planned for the near future. This type of machine should prove to be more durable and have more longevity in a continuous grinding operation. In addition, instead of blowing material into a van as with a chipper, the grinder utilizes an inclined conveyer for top loading vans, which should improve payload efficiency.

Bale Measurements

Twenty-four bales were weighed and measured to determine circumference, volume, and density (Table 4).

Two bales fell apart during transport from the woods to the landing, so they were not included in the bale measurements summary. Samples were collected from ten bales to quantify moisture content, heat value, and ash content (Table 5). Means in parenthesis are for comparison and represent values calculated from three samples by Herty Advanced Material Development Center (Ali, O.F. 2008). Oven-dry heat of combustion was calculated using heat value and moisture content of the material after drying.

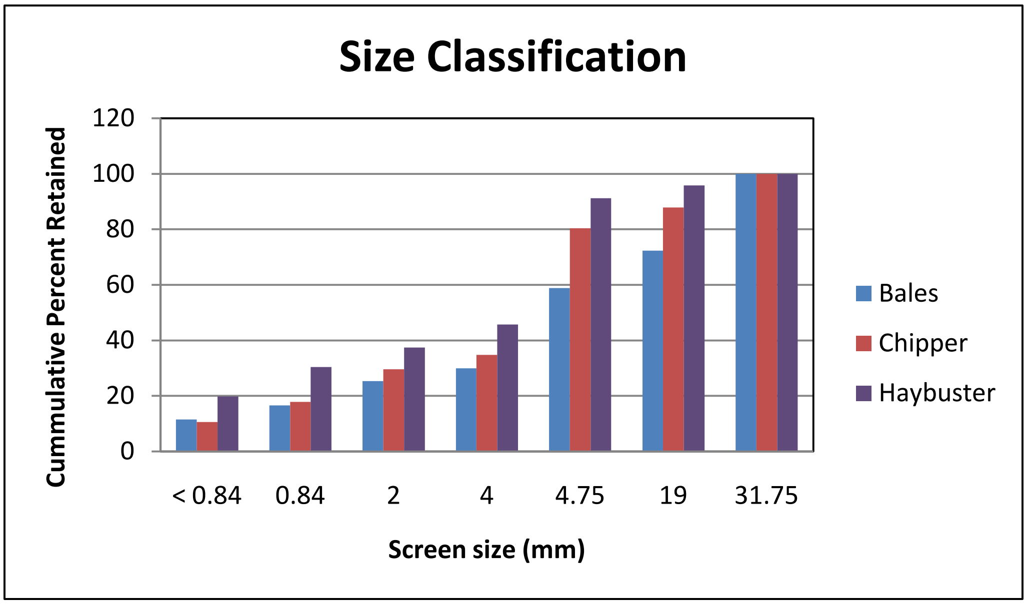

Figure 2. Size classification of material displayed as cumulative percent of total weight.

Table 4. Summary of bale measurements for the FLD WB-55.

Variable	*N*	*Mean*	*SD*	*Min*	*Max*
Horizontal diameter (ft)	24	4.2	0.15	4.0	4.6
Vertical diameter (ft)	24	4.0	0.19	3.6	4.3
Width (ft)	24	4.1	0.08	4.0	4.2
Weight (lb)	24	991.6	54.62	893.5	1063.5
Circumference (ft)	24	12.9	0.40	12.1	13.7
Volume (ft^3)	24	53.6	3.43	47.7	62.4
Density (lb/ft^3)	24	18.6	1.53	16.3	21.3

Oven-dry heat of combustion averaged 8629 Btu/lb from samples collected from ten bales. This value is comparable to the heat content of pine stemwood, tops, stumpwood, and cones, which have heat values in the range of 8,000 to 8,600 Btu's/lb (Koch, 1972). This suggests that the heat content of baled understory vegetation is similar to that of pine stemwood, even though bales contain a significant amount of non-woody material (Klepac and Rummer, 2009).

Table 5. Moisture content, heat value, and ash content summary.

Variable	*N*	*Mean*	*SD*	*Min*	*Max*
Moisture content (% wet-basis)	10	35.0 (41.2)	3.49	30.5	41.2
Oven-dry heat of combustion (Btu/lb)	10	8629 (8595)	90.4	8506	8751
MMBtu/bale (wet)[1]	10	3.0	0.29	2.6	3.5
MMBtu/bale (dry)	10	5.5	0.41	4.9	6.1
Ash content (%)	10	1.8 (2.5)	0.54	1.0	2.5

[1] MMBtu = $1x10^6$ Btu's.

System Costs

A machine rate, which reflects the average yearly cost over the useful life, was calculated for all equipment. These rates were then used to calculate a system balance and cost (Table 6). Assumptions used to calculate machine rates included a 6-year life for the Fendt 818 tractor, with a salvage value of 20 percent of the purchase price and a fuel consumption rate of 0.019291 gal/hp-hr (Klepac and Rummer, 2009). A repair and maintenance rate of 100 percent of depreciation, an 8 percent interest rate, an insurance rate of 3.5 percent of the purchase price, and a lube and oil rate of 36.8 percent of the fuel cost were used (Brinker, et.al., 2002). For the FLD WB-55 baler, a 4-year life, a 25 percent salvage value and an insurance rate of 2 percent of the purchase price were used (Brinker, et.al., 2002). A rate of 150 percent of depreciation for repair and maintenance and lube costs was assumed (Savoie, 2008).

The cost to forward bales from woods to landing was calculated for a 4-wheel and 6-wheel forwarder. For the 4x4 forwarder (9.6-ft bunk length) a payload of 10 bales was assumed, which consisted of bales stacked two wide, two long, and two high, with two on the top, with an estimated turn time of 20 minutes (Klepac and Rummer, 2009). The 6x6 forwarder (16-ft bunk length) had an estimated payload of 20 bales, which consisted of bales stacked two wide, four long, and two high, with four on the top, and an estimated turn time of 30 minutes ((Klepac and Rummer, 2009).

Table 6. System balance summary.

System	*Machine*	*# of Machines*	*Machine (tons/SMH)*	System ($/SMH)	**($/ton)**	**($/bale)**	**($/MMBtu)**
Baler w/ 4-wheel forwarder	Tractor/Baler	2.0	10.22	241.30	23.61	11.72	1.38
	Forwarder	1.0	10.54				
Baler w/ 6-wheel forwarder	Tractor/Baler	2.7	13.80	324.01	23.48	11.66	1.37
	Forwarder	1.0	14.06				

CONCLUSIONS

The FLD WB-55 baler was successful in producing bales from understory biomass from a 28-year old pine plantation. Performance improved significantly after improvements were made following the October 2008 trial. Productivity increased from 5.2 bales/PMH to 14.7 bales/PMH, which reduced the in-woods cost from $43/gt to $17/gt.

Improvements to the baler were also made after March 2009. Included in these changes were the replacement of the tires with 500-22.3/60 sized tires, an increase in reliability, and improvements to make routine maintenance much easier. After these modifications were made, the baler was evaluated while working in willow and poplar plantations in Ontario during November 2009. Production at one site averaged 31 bales/hr for willow and 37 bales/hr for poplar (Savoie and others, 2010). Estimated yields were 14.7 gt/ac at the willow site and 19.1 gt/ac at the poplar site.

One issue to consider is the application of treatments over time. If re-baling is planned every 3 years to control growth, volume per acre cut in subsequent treatments may be less than in the initial pass, resulting in higher a cost per ton. However, if the mow-and-tow treatment is not employed periodically, re-growth will quickly overcome the effects of the treatment and there will be little benefit to wildlife, hunting, or fire. These sorts of questions are critical to understand what stand conditions are acceptable for baling treatments.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation to Supertrak, Inc., The Langdale Company, and Anderson Group Co. for their cooperation during this project. Their generous support made this project a success.

REFERENCES

Ali, O.F. 2008. Understory processing report. Herty Advanced Materials Development Center.

Canto, J.L., Rummer, B., et.al. 2008. Evaluation of two baling systems for harvesting biomass on the Osceola National Forest, Florida, United States. In: Proceedings of the 31st Annual Meeting of the Council of Forest Engineering, S.A. Baker, M.C. Bolding, and W.D. Greene, eds. Charleston, SC, June 2008.

Fridley, J.L. and T.H. Burkhardt. 1984. Densifying forest biomass into large round bales. Transactions of the ASAE. 27(5): 1277-1280. 373.

Klepac, J. and B. Rummer. 2009. Evaluation of the WB55 Bio-baler for baling woodsy biomass in a forest application. In: Proceedings of the 2009 SAF National Convention, Orlando, FL. Bethesda, MD.

Koch, P. 1972. Utilization of the southern pines. USDA Agric. Handb. 420. USDA For. Serv., South. For. Exp. Sta.

NRCS, 2009. http://www2.ftw.nrcs.usda.gov.

Savoie, Philippe Dr. 2008. Correspondence.

Schiess, P. and K. Yonaka. Baling – A new concept in residue handling. 1983. Proceedings: Timber harvesting in the central rockies-Problems and opportunities. Coop. Ext. Serv., Colorado State University, Fort Collins, CO. 214-240.

Stokes, B.J., D.L. Sirois, and S.L. Woodfin. 1987. Preliminary evaluation of steel-roller round baler for woody biomass baling. In: Proceedings of the 9th Annual Meeting of the Southern Forest Biomass Workshop; 1987 June 8-11; Biloxi, MS. Mississippi State, MS: Department of Forestry; 167-174.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

STUDY ON THE EFFECTS OF SHIFT SCHEDULE ON FOREST ENTREPRENEUR PERFORMANCE

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Abstract
For various reasons, forest entrepreneurs in Eastern Canada run their operation day and night. Most commonly, two operators run the equipment more or less continuously on 12-hour shifts, for a total of 24 scheduled hours. While this practice has been common for at least 30 years in Canada, few quantitative studies in forestry are available to guide practitioners when deciding on a work schedule. The current approach used to decide on operating time is not based on scientific evidence and it remains difficult to report precisely on the advantages and risks associated with a specific schedule. It is with this in mind that a study was designed to measure the effects of two shift systems on the performance of harvesting operations. The first system was based on 12-hour day and night shifts; the second on 10-hour day and night shifts. An intense data collection process was put into place. Two harvesting teams were selected. The tests were conducted for a period of two weeks, one for each shift work schedule. A total of four workers were observed. A sleep logbook was distributed to document the sleeping periods. The “Standard Shiftwork Index” (Folkard, 1988) complemented these logs. In addition, each operator was asked to wear an “actiwatch”, which objectively recorded sleep quality. Two cameras were installed in each machine to record the operator’s activity. One camera was focused on the operator’s face to record signs of drowsiness. The other camera was aimed at the harvesting head and allowed us to record external activities. Each machine was equipped with a data recorder. Finally the operators used a handheld computer to take a psychomotor vigilance task (PVT) test every hour during the shift. Our results indicate that reducing shift duration by two hours provides some benefits to the operators. More significant benefits could be achieved by postponing the start of the morning shift and by reviewing break duration and position within the work day.

INTRODUCTION

In Québec, as in other large forest product producing countries, harvesting mechanization has encouraged the emergence of logging contractors (MRNF, 2006, Drolet and LeBel, 2010). These new forest entrepreneurs have modified the structure of the forest economy. Their presence has helped determine wood supply costs and maintain competitiveness within the industry (Hailu and Veeman 2003). Regardless, fitted with larger, more sophisticated and costly operating equipment, these entrepreneurs and their clients consider it necessary to maximize operating hours.

In Canadian forests, traditional day work is often replaced by work schedules that include multiple and extended work shifts. The main reason for using such work schedules in the forest industry remains financial. Indeed, such schedules are appropriate when capital investments are high and forest equipment can rapidly become obsolete.

Forest operations in Scandinavia, Canada and certain US states near the Great Lakes and in Maine (Mitchell and Gallagher 2006), have been using non traditional work schedules for many years to increase production. Entrepreneurs in Eastern Canada use a wide variety of work schedules. The number and length of shifts commonly vary from one business to the next, within a same business, and even within a division or logging camp. According to a survey of FERIC members in Eastern Canada conducted in 1991 (Golsse, 1992), respondents reported 46 different work regiments. The vast majority (71%) reported working 5 days and most mechanized operations used schedules which included only one (37%) or two (51%) shifts per day. Results of a survey of harvesting forest entrepreneurs conducted in the fall of 2006 (PREFoRT 2007) confirm these findings concerning work week duration. Indeed, 79.2% of respondents reported using 5-day workweeks with two days off. In 2006, at least 38% of harvesting entrepreneurs operated using more than one shift per day. As opposed to Golsse's study (1992), PREFoRT results also included entrepreneurs active in private forests where nightshifts are much less prevalent.

Of course, many possibilities exist when it comes to the distribution of work shifts and scheduling. It is difficult for an entrepreneur to choose which might be the best schedule to maximise production, minimise costs and respect the operator's safety and well-being. When deep in the woods, scheduling is often determined according to travel distance and even opening hours at the camp cafeteria! Maximising the machinery's utilisation also motivates entrepreneurs to have the equipment in function as much as possible each day. However, we deplore the lack of available data that would confirm the true effects of extended work shifts, as well as determine the pros and cons associated with each option. Numerous variables are involved in the choice of the most productive work schedule. It is thus important to evaluate the influence a given shift schedule has on performance.

The general objective of this study is to determine the effects of two shift schedules on the performance of forest entrepreneurs. Two types of shifts were studied: a 12-hour and a 10-hour shift. Two harvesting teams collaborated, each owning a single harvester processor.

METHODOLOGY

Data was collected during three weeks in September and October of 2008 (29 September – 3 October; 6 – 10 October, and 27 – 31 October). The measures used in this study are based on both objective and subjective observations.

Firstly, sleep logbooks were handed out in order to collect information such as operators' wakeup and bedtime, levels of tiredness and drowsiness before going to bed and after waking up, as well as information on sleep quality (sleep latency, night wakening…). In association with these logbooks, the "Standard Shiftwork Index" questionnaire (Folkard, 1988) was also used to analyse other elements such as the operators' sleeping habits.

Secondly, actiwatches (Gibbs et al, 2007 - Bio-Lynx Scientific Equipment) which monitor sleep duration and quality were worn by the operators during both tested shifts. Video recorders were also installed in the harvester's cabin to determine periods of drowsiness by operators. Electronic chronographs also made it possible to continuously record equipment movement and thus measure working hours. Also, the number of trees harvested was calculated thanks to continuous video recordings from a second camera within the cabin. Finally, the last objective measure for this study was the Psychomotor Vigilance Task test (Sylvia et al, 2004) used to measure operator performance.

PVT tests were conducted during day or night shifts, for every hour the operator was at the controls of the machine. This data was collected at the end of each shift by experimenters. Video recordings were also collected during the short meetings at the beginning and end of each shift. Finally, data from the actiwatches was downloaded at the end of each week.

RESULTS

The data collected and observations made during the study have yielded results concerning sleep quality and duration, alertness when operation machinery and production levels.

- **SLEEP**

Average sleep duration obtained from sleep logs indicate that nightshift operators sleep more than dayshift ones, independent of the shift schedule used (Table 1). This difference is also noted when using data from the actiwatches (Table 2). Note that in the 10-4-10 work schedule, it is the machine owner (the entrepreneur) who operates the machine during four hours.

Table 1: Sleep log data

	Schedule 10-4-10		Schedule 12-12	
	Dayshift (5am-3pm)	Nightshift (7pm-5am)	Dayshift (5am-5pm)	Nightshift (5pm-5am)
Sleep duration	6:00 ± 1:12	7:47 ± 1:13*	6:58 ± 1:43	7:51 ± 1:14 *
Sleep latency	1:02 ± 0:30	0:12 ± 0:07	0:34 ± 0:15	0:08 ± 0:02

* ($p<0.001$) day vs. nightshift for Schedule 12-12 and Schedule 10-4-10

Also, whether we look at data from the actiwatches or the sleep logs, sleep latency is more important in dayshifts than nightshifts for 10-4-10 schedules. Let us note that dayshift operators, whether on the 10-4-10 or 12-12 schedule, plan their wakeup in order to start the day early at 5 o'clock in the morning (Table 3). On the other hand, 75% of nightshift operators wake up without an alarm clock. Finally, over 50% of operators reported waking once or more often after their nightshift on the 10-4-10 schedule or their dayshift on the 12-12 schedule. However, this data was not corroborated by the actiwatches which recorded wakeups of 1 minute on average.

Table 2: Actiwatch sleep data

	Schedule 10-4-10		Schedule 12-12	
	Dayshift (5am-3pm)	Nightshift (7pm-5am)	Dayshift (5am-5pm)	Nightshift (5pm-5am)
Sleep duration (actiwatch)	5:57 ± 1:08	7:38 ± 1:21*	6:56 ± 1:29	7:54 ± 1:08 *
Sleep latency (actiwatch)	0:55 ± 0:41	0:14 ± 0:05*	0:30 ± 0:11	0:05 ± 0:05 *
Wake up during sleep (actiwatch)	0:01 ± 0:00:12	0:01 ± 0:00:08	0:01 ± 0:00:21	0:01 ± 0:00:22

* ($p<0.001$) day vs. nightshift for Schedule 12-12 and Schedule 10-4-10

Table 3: Sleep quality from sleep log data

	Schedule 10-4-10				Schedule 12-12			
	Dayshift (5am-3pm)		Nightshift (7pm-5am)		Dayshift (5am-5pm)		Nightshift (5pm-5am)	
Wakeup type	Planned	Normal	Planned	Normal	Planned	Normal	Planned	Normal
	80%	20%	22%	78%	64%	36%	25%	75%
Wakeup during sleep	No for 100% of respondents		Yes 62.5 % No 27.5 %		Yes 57 % No 43 %		yes 43 % No 57 %	

- **RESPONSE TIME**

The evolution of average response time every two hours (Figure 1 and 2), for day and nightshifts indicate the presence of circadian rhythmicity. In accordance with literature on the subject, response time increases after lunch and towards the end of the night, indicating a decrease in the operator's ability to react promptly to visual and reasoning stimuli.

For dayshifts, an increase in response time was observed towards the end of the shift suggesting cumulative fatigue after more than 10 or 12 hours of service (Figure 1). For nightshifts, two peaks appear between 10 PM and midnight and towards the end of the shift at 4 AM (Figure 2).

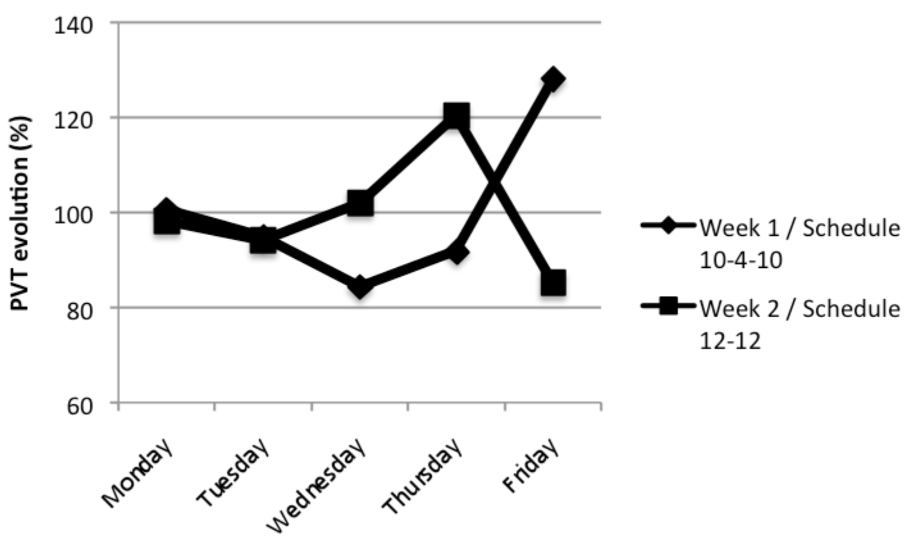

Figure 1: Reaction times for dayshifts. Evolution based on the calculation of average (100%) daily response time (under 500ms).

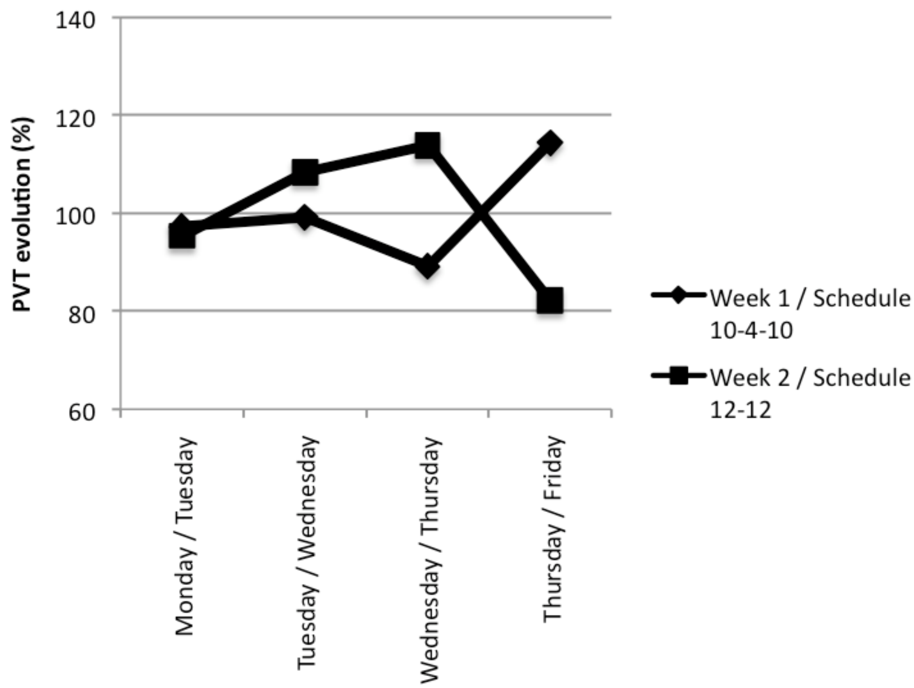

Figure 2: Reaction times for nightshifs. Evolution based on the calculation of average (100%) daily response time (under 500ms).

- **PRODUCTION**

The number of trees cut, as observed with our video recordings, was counted every two hours for both 10-4-10 and 12-12 schedules. Figure 3 illustrates an evolution of the production throughout the dayshift, while Figure 4 does the same for the nightshift.

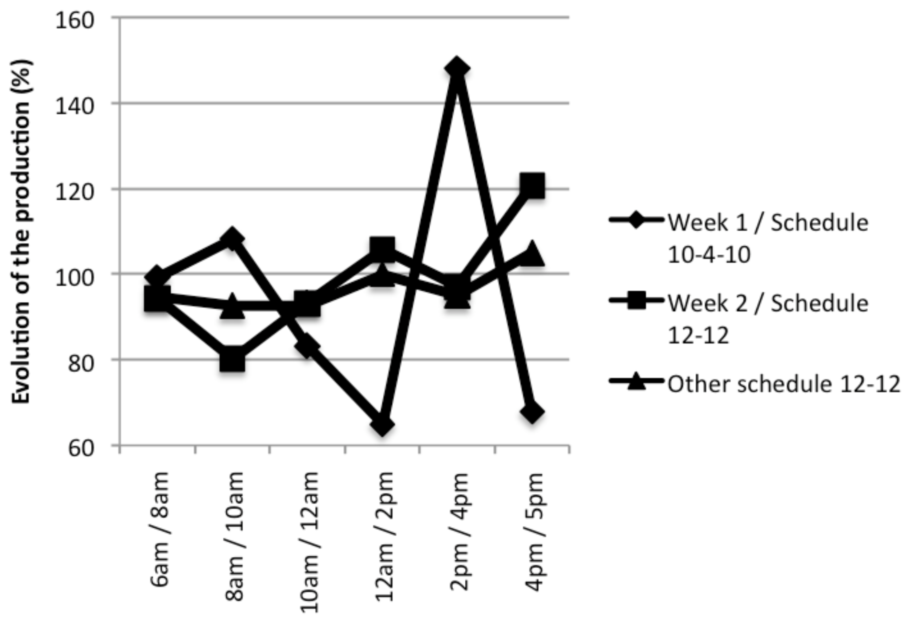

Figure 3: Evolution of the number of trees cut for dayshifts. Evolution based on a calculation of the average (100%) daily number of trees cut.

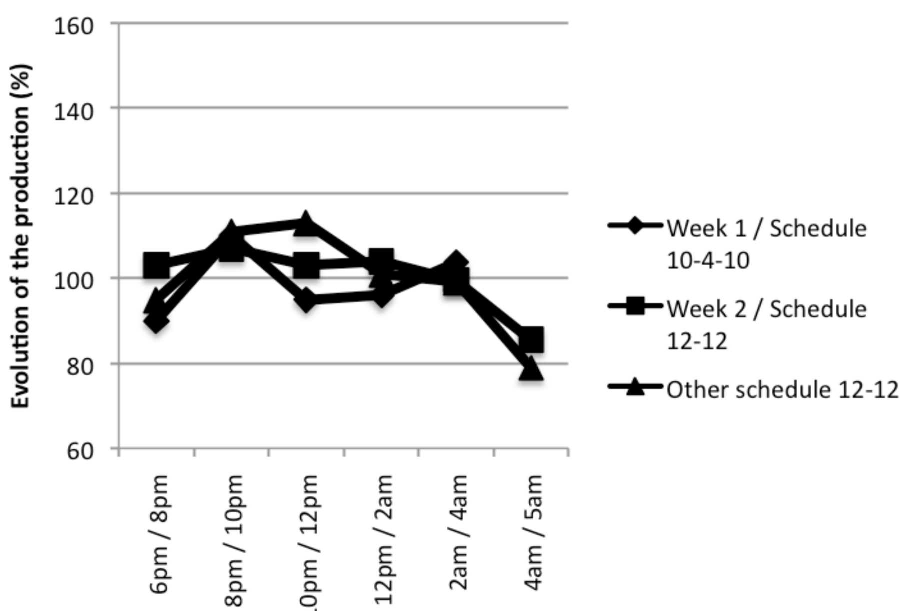

Figure 4: Evolution of the average number of trees cut for nightshifts. Evolution based on a calculation of the average (100%) daily number of trees cut.

For dayshifts (Figure 3), the number of trees cut evolves inversely to the response times. This indicates a decrease in production when the response time increases after lunch (noon-2PM) and towards the end of the shift (4-5PM). This evolution is however reversed for dayshifts of the 12-12 schedule.

During nightshifts, whether 10 or 12-hour long, the number of trees cut continuously decreases throughout the shift. Although response times are longer towards the end of the 10-hour shift (4-6AM) and between 10PM and midnight, these variations do not affect production as production continuously decreases throughout nightshifts of both 10-4-10 or 12-12 schedules.

When associated with data from another camp (this data was collected by FERIC researchers and present averages on a three-week basis for a 12-12 schedule), the decrease in trees cut can be observed in the same manner for the nightshift (Figures 3 and 4). For the dayshift, the evolution of trees cut from another harvester processor (from another camp) follows that of the 12-hour shifts and remains relatively stable throughout the day (Figure 3).

DISCUSSION

The constant monitoring of two shifts of 10 and 12 hours over a period of 2 weeks has led to many convincing results and, in certain cases, will lead the way to future, more precise studies. As a whole, the findings are in accordance with scientific literature on the subject (Åkerstedt, 1988 ; Aschoff,1978).

Production rhythm of trees cut, observed on the video recordings, follows the performance of operators as evaluated with the PVT tests. Towards the end of the nightshift (4-6AM) as well as after lunch (noon-2PM), whichever schedule is chosen, a decrease in production can be observed while operators' average response time increases. These variations coincide with data from the literature which report important decreases in vigilance for these two periods.

When comparing data from both schedules, one notes greater variation in response times for 10-hour shifts (± 30%) compared to 12-hour ones (± 10%). These fluctuations are also noticeable in the number of trees cut during dayshifts.

Furthermore, results indicate longer sleeping periods for nightshifts than dayshifts. The influence of the location (a camp more than 200 km from civilisation) as well as the camp's structure may explain these results. Indeed, in spite of diurnal sleep, the camp offers better sleeping hygiene to what is available in town. The absence of family obligations also remains an important factor in providing operators with more than 7 hours of sleep. However, lack of sleep was noted at the beginning and end of the work week for nightshift operators. That is, on Mondays and Fridays when they must make a transition between their weekly night schedule to a more "normal" schedule during the weekend. This transition period would need further study.

As a whole, these variations in sleep, performance and production highlight two important facts. Firstly, there does not seem to be a type a schedule more advantageous than the other for these operators. Secondly, these forest workers do not seem to adapt to these types of schedules.

These facts highlight the importance of modifying the current system in order to stabilise production pace and hopefully increase it. Indeed, our study has not observed important differences between 10-hour or 12-hour schedules. It is thus difficult, without a complete economic analysis, to choose the best schedule. The model proposed by Murphy aand Vanderberg (2007) could provide insights to this means. However, certain recommendations could be taken into consideration in order to improve the operator's ability to adapt to these schedules. Two major changes may be suggested: starting a shift a little later than 5AM and ending the night shift earlier, like at 3 AM.
It would also be possible to decrease cumulative fatigue of operators even while preserving 24-hour schedules (2x12 or 2x10). Rigorous break management scheduled at times where

their effect would be most beneficial appears to be necessary. Moreover, this conclusion meets recommendations by Nicholls et al. (2004)

CONCLUSIONS

Through our study, we have noted that nightshifts workers enjoy longer and better sleep quality, whether they work 12 or 10-hour shifts. We explain these results by the fact that day workers we observed had to get up very early. Also, since nightshift workers sleep little on Mondays, they may make up for lost sleep during the week. In any event, we have observed cumulative fatigue during the weekend. As for production, the number of trees cut is higher during the first part of the night, while dayshifts report higher production during the last part of the shift. It would seem that the dayshift, as it was observed, begins too early and provokes cumulative fatigue. Also, the end of the nightshift is less productive and operators show decreased vigilance. We would thus recommend, whenever possible, to start the dayshift later and end the night shift earlier.

REFERENCES

Åkerstedt T (1988). Sleepiness as a consequence of shift work. Sleep, 11, 1, pp. 17-34.

Aschoff J (1978). Features of circadian rhythms relevant for the design of shift schedules.- Ergonomics, 21, 10, pp. 739-754

Barton J, Folkard S, Smith L R, Spelten E R, Totterdell P A. (1988) Standard Shiftwork Index. Shiftwork Research Team, MRC/ESRC Social and Applied Psychology Unit,.

Drolet, S., L. LeBel. (2010). Harvesting entrepreneurs, perception of their business status and its influence on performance evaluation. Forest Policy and Economics. 12, pp. 287-298.

Gibbs, Michelle, Hampton, Shelagh, Morgan, L., Arendt, J (2007). Predicting Circadian Response to Abrupt Phase Shift: 6 Sulphatoxymelatonin Rhythms in Rotating Shift Workers Offshore. J Biol Rhythms, Vol. 22; p. 368

Golsse, Jean-Marie (1992). Shifting regimes [shift lengths in harvesting operations]. FERIC, TN-24, July 1992.

Hailu, A. and Veeman, T.S. (2003) Comparative analysis of efficiency and productivity growth in Canadian regional boreal logging industries. Can. J. For. Res. 33, pp. 1653-1660

Mitchell D. and Gallagher T. (2006) Extended working shifts: are they applicable to the Southeastern United States? The 29th Council on Forest engineering Conference. Coeur d'Alene, Idaho, July 30-August 2, 2006. W. Chung and H.S. Han, editors. pp. 513-522.

MRNF, (2006). Procédés de récolte des bois utilisés dans les forêts du domaine de l'état - Rapport annuel 2004-2005. Ministère des Ressources naturelles et de la Faune. Bibliothèque nationale du Québec, 40 p.

Murphy, G. and Vanderberg M. (2007) Modelling the economics of extended shift 24/7 forest harvesting. NZ journal of Forestry. 52(2):14-19.

Nicholls, L. Bren, N. Humphreys. (2004) Harvester Productivity and Operator Fatigue: Working Extended Hours. International Journal of Forest Engineering 15, 4, pp. 57-64.

PREFoRT (2007). Résultats préliminaires - Sondage sur les entrepreneurs forestiers. Québec, Canada: Université Laval (available on-line :www.prefort.ulaval.ca).

Sylvia L, Lamond N, Dorrian J, Roach G and Dawson D.(2004) The validity of psychomotor vigilance tasks of less than 10-minute duration. Behavior Research Methods, Instruments, & Computers 36, 2, pp.339-346

Temperatures and sparking from operation of high-speed disk saws

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Operation of harvesting equipment in dry, western stands has been anecdotally linked with forest fire ignition and land managers have shut down harvesting in some cases because of it. This study was conducted to characterize two of the potential ignition sources from operating hot saws. Saw temperatures were recorded in two modes: a static mode that looked at overall temperature increase of the disk with operation, and a dynamic mode in which the temperature at the saw/ tree interface during the severing process was measured. Static temperature increases were on the order of 20-40 degrees C above ambient. Dynamic temperature measurements also showed an increase, but the magnitude was only on the order of 2-3 degrees C above the current operating temperature. Much higher temperatures increases were recorded when disk saws were stopped on stumps, in most cases the temperatures of the stumps increased above levels that would cause ignition in dry conditions. Spark formation was investigated using a high-speed circular saw in a fixture that allowed momentary, controllable contact between a rock sample and a carbide-tipped blade. The contact was filmed using high-speed cameras and the number of sparks over a precise interval that traveled in excess of 4 cm was measured. Numbers of sparks, and characteristics of spark travel, were found to be affected by rock type, with basalt showing the highest numbers.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Mileage savings from optimization of coordinated trucking[1]

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Abstract

Data on mileage driven and loads delivered were collected from a log trucking firm hauling for 5 loggers to 9 consuming mills. Routes were assigned by a supervisory person and were not optimized. On average over the week of testing, the schedule achieved a loaded mileage proportion of 57%. A route optimization system was also used to assign delivery schedules and it achieved a loaded mileage proportion of 66%, significantly higher than the human-assigned dispatch ($P < 0.02$), and potentially saving the firm by up to 15,000 miles per year. Feasibility of the generated optimal schedules was a concern, but could not be directly evaluated. Instead, specific characteristics of routes that might be considered optimal and feasible were selected, and the generated solutions evaluated for whether or not they had those traits. Optimal solutions tended to a) deliver loads from multiple loggers on single days, and b) replicate a few, shorter routes between trucks, both of which were considered traits of feasible schedules. It was concluded that the optimization system was of potential benefit in reducing transport costs of coordinated trucking systems.

Introduction

Tree-length loggers of the US South have been slow in adopting technological solutions to increase efficiency of log transport. This has been despite the fact that commercial transport optimization solutions tailored to the logging industry have been developed (see e.g. Trimble BlueOx). In general, most loggers are reluctant to spend money on non-traditional technology without the certainty of a return on their investment, either in lower costs or increased hauling capacity.

Numerous studies have shown increases in log transport efficiency from application of optimization methodology (e.g., Shen and Sessions, 1989; Weintraub and others, 1996; Murphy, 2003). Most studies, however, were for situations other than found in the US South where log transport is typically structured to serve a single logger hauling to a handful of mills. The collaborative approach to hauling timber where multiple loggers use a pooled trucking resource is just now being adopted in widespread fashion, most commonly using a single human dispatcher to coordinate load

[1]The authors wish to express their thanks to the USDA Forest Service, Forest Operations Research Unit in Auburn, AL for support of the research performed in this project.

allocation (Mendell and others, 2006). Current practice does not take advantage of the additional potential benefits of computer optimization of truck schedules.

Log truck allocation can be modeled using combinatorial methods and solution techniques to constrained optimization of the resulting problems have been proposed. Most of these methods, however, have not accounted for time in the models but rather take all trucking and load resources as being available at any time during a day (Taillard and others, 1997). This is a simplification that makes solution of the problem much more tractable, but one that also may result in solutions that are completely infeasible, i.e. schedules that cannot be implemented in practice.

This study was done to investigate the increment in log transport efficiency that might be achievable were route optimization technology implemented in a pooled log delivery system, that is a system that hauls timber from multiple loggers to any of a number of mills. The experiment was intended to assess the reduction in mileage that can be realized from application of optimization to log truck scheduling, and also to determine the feasibility of the optimal solutions. The specific objectives of the study were to:

- Characterize the baseline loaded mileage efficiency of an existing pooled log transport system using human dispatch of trucks.
- Using the identical daily delivery schedules, apply optimization methods to decrease unloaded mileage and assess the feasibility of the optimal solutions.

Methods

Data for the study were collected from a single log delivery trucking firm over the course of one week (Monday to Saturday) in February 2008. The firm operated about 12-20 trucks, depending on the day of the week. Of these trucks, a few were typically employed moving equipment or making deliveries of other commodities, but most were used exclusively for log transport. Only those trucks delivering logs were considered in this study, but there were instances where both types of deliveries were made by a single truck on one day. In those cases, that portion of the shift that was clearly log delivery was included in the analysis. Over the week, a total of 17 different trucks delivered 257 loads from 5 logging operations to 9 destinations.

All trucks were centrally dispatched by a person who did not use any form of optimization in scheduling other than their experience. Trucks varied their routines at the end of their shifts, some returning to a central yard while others ended their days at some other location, presumably at home. The trucks not returning to the yard typically were loaded at the end of the day and it was further presumed there was a mileage advantage gained by not returning to the dispatch yard at night. On any given day 4 to 9 trucks ended the shift loaded.

All movements of trucks were captured using a global positioning system (GPS) that recorded location after a truck had moved a distance greater than a fixed threshold value. Along with location, speed and time were also recorded. The raw GPS data were gone through manually to extract times and cumulative distances for each stop at either a mill or logger. Distances between mill and logger destinations were accumulated and averaged, as was travel time between the locations to calculate an average speed. Time spent at each location was also noted and averaged to come up with a logger- and mill-specific service (loading/unloading) time. Table 1 is a summary of distance and time information used as input to model the trucking system.

Table 1: Summary of mileage and service times for loggers and mills.

	Mill	Crew 1	Crew 2	Crew 3	Crew 4	Crew 5	Service Time (hours)
Service Time (hours)		1.09	0.67	0.7	0.89	0.88	
Distance (miles)	1	37.5	40.2	31.6	9.7	12	0.37
	2	92.7	87.4	79.5	53.4	45.6	0.49
	3	41.7	22.9	14.3	29.2	47.9	0.48
	4	26.5	25.6	40.3	19.8	28.9	0.89
	5	58.3	51.3	51	28.3	20.6	0.79
	6	52.7	47.6	28.7	26.7	45.9	0.97
	7	53.9	53	46.6	24	22.8	0.33
	8	144	122	88,4	78.8	79.1	0.52
	9	53.1	39.2	29	27.1	44	1.57

The optimization of routes was carried out on intraday truck movements only. A normal operating day began with the trucks leaving from the dispatch yard in the morning and first traveling to a logger location to pick up a load. The final movement of the day was normally a return trip from a mill to the dispatch yard. Neither of these moves were counted in the total mileage driven by a truck during the day.

The choice to not include trips to or from the dispatch yard in the optimization was made because the trucking system dispatcher seemed to make choices in route selection that were designed to minimize mileage across successive operating days. These moves typically involved leaving a truck loaded at the end of the day and not having it return to the dispatch yard. It was presumed that the operator selected a final load for some trucks for which the delivery to a mill took the driver past their home and they stopped for the night along the route. Although this was the presumed reason for some trucks not returning to the dispatch yard in the evening, this fact could not be verified. Without information on home locations of the drivers it was not possible to include these choices into the optimization scheme. Similarly, those trucks remaining loaded from the day before did not leave in the morning from the dispatch yard but went directly to a mill and these movements were not included in the optimization either. All beginning- or end-of-day moves for all trucks were therefore ignored. It was felt this comparison was the most realistic between the two dispatch systems.

The optimization of truck routes was carried out using a simulated annealing solution method for the system model as proposed in Haridass (2009). The objective function of the model was simply a summation of mileage used to deliver a set of loads and it was minimized subject to numerous constraints. The constraints restricted the solution to those that obeyed the laws of physics with regard to space and time, limited the operating time of a truck to no more than 10 hours per day, and allowed only integer numbers of loads to be delivered.

The simulated annealing solution method required a means of evaluating the relative merit of two solutions, allowing a choice to be made between them. A potential solution was evaluated using a simulator to 'run' it, then collect data on its performance. A 'fitness function' was then applied to four metrics calculated from the simulated delivery schedule. Those metrics included:

- Number of unloaded miles.
- Number of undelivered and 'phantom' loads.
- Waiting time at logging decks or mills.
- Number of trucks not meeting the constraint on working time.

Each of these metrics was multiplied by a weighting factor and summed. Those solutions having smaller penalty function values were regarded as being 'better' in some sense than those with larger values. The 'phantom' load terminology was a penalty applied to any load that was delivered but was not on the original daily schedule. These types of loads could result from the methods used to generate new solutions in the iterative simulated annealing process described below.

The simulated annealing method required a set of improvement operators by which new solutions could be derived from previous ones. These operators either added or deleted loads for a single truck, exchanged or shifted loads between trucks, or stopped a truck at a given point. New routes evaluated during the simulated annealing process were always generated from application of one or more of these operators between iterations. Once generated, a new schedule was simulated and evaluated using the fitness function then compared to the previous solution. If better, the new schedule was retained (with a certain probability) and another iteration performed until no further improvement was detected.

Results

Comparison of Observed and Optimal Routes

Loaded miles as a percentage of total driven for the non-optimized routing averaged 57 percent (table 2). This value did not include mileage to and from the first and last destinations so the overall true route efficiency would be lower. It did indicate, however, that the current scheme used to dispatch trucks was relatively effective. For static assignment of trucks, that is allocating all trucks to haul for a specific logger, this intra-day route efficiency would be near 50 percent by definition.

Application of the simulated annealing optimizer resulted in an average intra-day route efficiency of 66 percent (table 2). The overall difference in total route length between allocation schemes was about 20 miles per truck per day and was significant (P <0.02). Assuming mileage for the trucking system observed in this study was indicative of its true average weekly rate and that the reduction in unloaded miles from route optimization could be realized for the entire year, the decrease in mileage for 50 weeks of operation would be over 15,000 miles.

Table 2: Summary of mileage by day with and without route optimization.

Route Optimization	Measure	Day						Avg.
		Mon	Tue	Wed	Thu	Fri	Sat	
None	Unloaded Miles	1119	1114	668	1236	868	726	955
	% Loaded Route Mileage	58	56	60	55	60	55	57
	Min Route Length (miles)	27	40	27	40	26	80	40
	Max Route Length (miles)	261	241	201	282	203	189	230
	σ Route Mileage (miles)	74	53	52	68	51	35	56
	Median Route Segments	6	5	5	7	6.5	5	6
SA	Unloaded Miles	650	723	338	812	673	620	636
	% Loaded Route Mileage	70	66	72	65	65	59	66
	Min Route Length (miles)	37	40	37	125	89	48	63
	Max Route Length(miles)	232	235	182	213	190	215	211
	σ Route Mileage (miles)	46	58	41	24	27	59	43
	Median Route Segments	6	6	5	6	6	5.5	6

Figure 1 shows a plot of the frequency of occurrence of route distances. A 'route' in this case referred to the transport schedule over one day for one truck. The route mileage distributions for the week were quite similar for both the observed system and the optimized routing scheme. In general, the optimized transport schedule tended to shift some mileage from the longest routes to more numerous, shorter routes, but there were relatively few routes over 200 miles to begin with and the change did not dramatically shift the distribution. Variability in daily mileage between trucks, as represented by standard deviation of route length, was lower for the optimized routing (table 2) in 4 out of 6 days also indicating that the optimized system tended to allocate mileage more uniformly between trucks on a daily basis.

Larger differences in route characteristics between the two optimization schemes were observed for the number of route segments, a segment being one mill-to-logger or logger-to-mill traverse. Median number of segments per route did not vary greatly between optimization schemes, and was equal (6) for data pooled among days. The distribution, however, shown in figure 2, was quite different with the actual transport schedule showing a broad range in the number of segments and the optimized scheme tending to use a more consistent number of segments per route. Nearly 70 percent of all transport schedules assigned using the simulated annealing optimizer included 6 or 7 route segments. From a management standpoint, the route optimization scheme, in addition to reducing unloaded miles, tended to distribute trips to the mill more uniformly among drivers. It also tended to smooth daily mileage between drivers, but to a lesser extent. These characteristics could be of benefit to a trucking firm if there were issues of inequity in compensation among drivers.

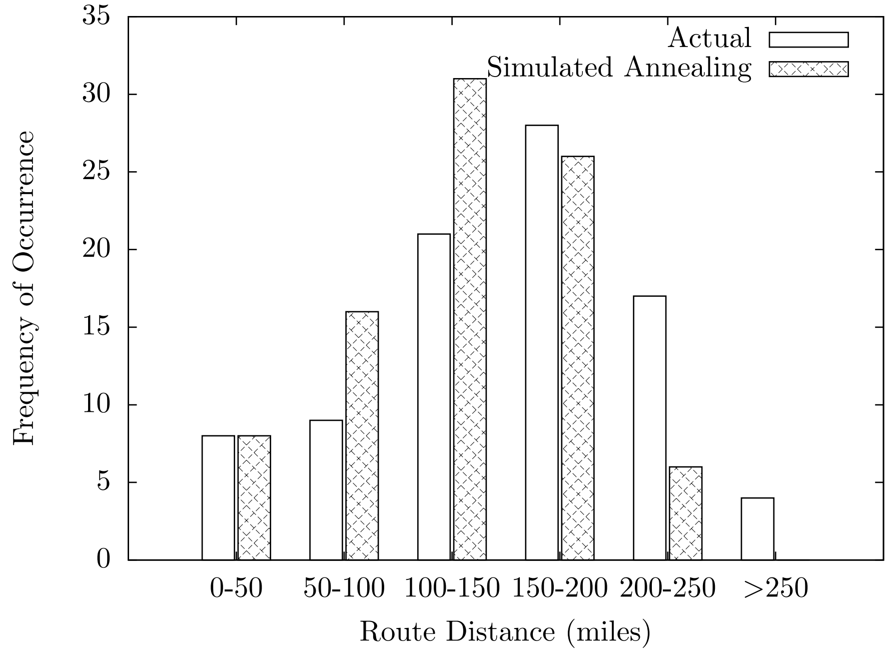

Figure 1: Frequency of routes of given lengths for original and optimized data.

The combination of a small set of loggers delivering multiple roundwood loads to a fixed (and also small) number of mills could imply that a single relatively short route applied across numerous trucks would form the core of a schedule minimizing total mileage to deliver all loads. It might also be reasonable to assume that this shortest route would, except in unusual circumstances, visit more than a single logger. An optimal delivery schedule, given these assumptions were correct, should perhaps exhibit both these characteristic of using replicated 'good' routes visiting multiple loggers on any given day. These characteristics should also be apparent when comparing optimized routes to the actual routes observed in this study and, in fact, the transport schedules generated using the simulated annealing optimizer exhibited both these characteristics. Figure 3 plots the distribution of the number of different loggers visited by each truck over the course of a day. The non-optimized routes had a high frequency of trucks (66%) that visited just a single logger during any given day. The optimized routes showed more diversity, with just under half visiting two, and 19% of routes visiting three. Table 3 shows the number of non-unique routes, meaning more than one truck drove a specific route, for a given day. For the entire week, the non-optimized schedule used four routes that were duplicated by multiple trucks. The optimized schedule used eight.

In figure 3, the number of trucks visiting zero loggers represented those that delivered a load held over from the previous day, then retired to the hub. Since there was no single 'hub' in the transport system, these beginning- and end-of-day moves were assigned in the optimization, but were excluded when calculating the mileage total. That is, the mileage to the logging deck for all final loads was counted on the day they were picked up, but the mileage to deliver the loads the next morning was never accounted for. It was interesting to note that, although there were typically five to seven of these loads held over each night, the optimizer did not prefer these zero-length

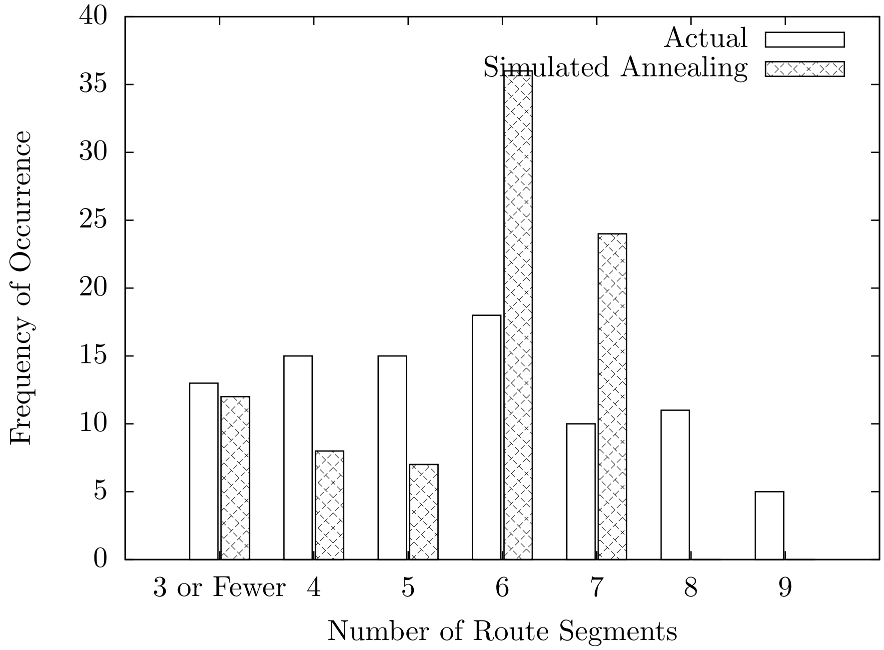

Figure 2: Frequency of occurrence of number of segments per route.

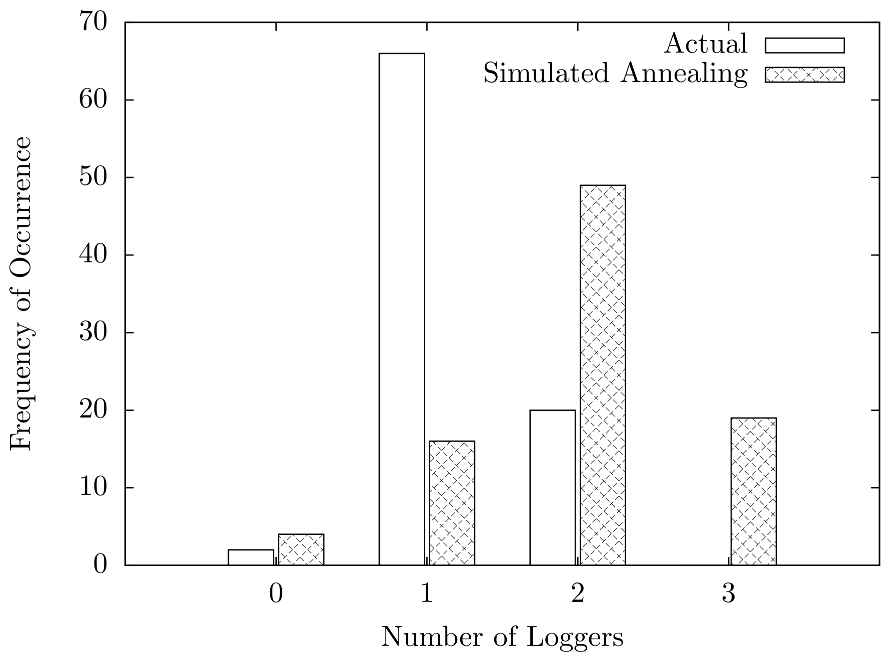

Figure 3: Frequency of occurrence of the number of loggers visited per route.

routes when generating transport schedules. In fact, the optimizer included this type of route in its schedule only two times more (4) than did the original routing scheme (2).

Effect of Waiting Time Variation

The simulated annealing route optimization scheme assigned a penalty to any waiting time spent queued either to be loaded or unloaded. The penalty affected the choice between two solutions and was included to prevent obviously infeasible solutions from being selected. In early tests of the optimizer without the waiting time penalty, for example, the solution would often send all trucks to a single logger first thing in the morning. Increasing the magnitude of the penalty, however, also negatively influenced the unloaded mileage of the optimal solution. Table 4 shows total time spent waiting and loaded travel miles percentage for a range of waiting time penalty values. The solutions were calculated for a single day (Monday). Increasing the penalty value decreased waiting time, but also decreased loaded miles percent.

The change in waiting time with penalty was large, but not linear. The largest penalty (10,000) reduced loaded mileage to just above 50 percent, indicating that the solution was almost entirely constrained. There was a large drop in loaded mileage between the penalties of 10 and 100, and waiting times also decreased by a factor of 3. Lower overall waiting time would imply higher utilization of trucks, but not necessarily earlier finishing times or lower operational costs. In fact, the largest waiting time penalty also resulted in 6 loads not being delivered in the 12-hour time window allowed for the simulations.

Effect of End-of-Day Constraints

The actual trucking system from which our operational data were derived allowed drivers to take trucks home loaded overnight presumably if it resulted in a shorter route to a delivery point the following morning. The initial optimization approach used in this study did not take advantage of these opportunities. To make the comparison between optimized and actual dispatch as fair and

Table 3: Number of non-unique pairs of individual truck routes per day, by optimization scheme.

Day	Non-Unique Pairs None	of SA
Monday	1	2
Tuesday	1	3
Wednesday	1	2
Thursday	1	0
Friday	0	1
Saturday	0	0

Table 4: Change in loaded miles traveled (%) and waiting time as a function of waiting time penalty.

Waiting Time Penalty	Loaded Miles Fraction	Waiting Time (h)
0.01	0.69	61.7
0.1	0.70	44.8
1	0.70	44.0
10	0.67	32.1
100	0.53	12.3
1,000	0.52	13.6
10,000	0.51	6.3

as transparent as possible, it had been decided to look simply at intraday truck movements. The actual dispatcher had an advantage that the computer optimization system did not have, namely information about home locations and about availability of loads to specific mills at the end of the day.

Specific, end-of-day transfers could have been included in the optimization scheme but this would have reduced overall effectiveness of the approach. Forcing a specific load to be picked up last would be an additional constraint on the solution and would most often result in less effective routing. It was decided, however, to see if the additional constraint imposed by a specific end-of-day pickup dramatically reduced the advantage of the optimization scheme over the actual system.

Results from application of the additional constraint were generated for two days of operation (Monday and Tuesday) and are summarized in table 5. Intra-day efficiency of the optimized system was lower when including the final extra pickup for both approaches, and by about the same amount (4%). Changes in the other measures of system performance were similar between the two schemes, with minimum and maximum route lengths not changing by a large amount and standard deviations increasing only slightly. It was concluded that, at least for these two days, an additional constraint on the solution did not materially affect the advantage gained from the optimization system developed for this study.

The solutions found when applying the extra constraint were not the same as those identified without the constraint. There were, however, some routes that were exactly the same between the two methods, a total of 5 for Monday and 4 for Tuesday.

Summary and Conclusions

Data on mileage driven and loads delivered were collected from a log trucking firm hauling for 5 loggers to 9 consuming mills. Routes were assigned by a supervisory person and were not optimized. On average over the week of testing, the system achieved a loaded mileage proportion of 57%. A

Table 5: Summary of mileage by day with and without route optimization. The solution in this case has been constrained to ensure that specific loads are picked up at the end of the day to be delivered the following morning.

Route Optimization	Measure	Day	
		Mon	Tue
None	Unloaded Miles	1239	1276
	% Loaded Route Mileage	55	53
	Min Route Length (miles)	26	40
	Max Route Length (miles)	261	281
	σ Route Mileage (miles)	77	70
	Median Route Segments	6	5.5
SA	Unloaded Miles	799	874
	% Loaded Route Mileage	66	62
	Min Route Length (miles)	40	78
	Max Route Length(miles)	213	205
	σ Route Mileage (miles)	50	34
	Median Route Segments	6	6

route optimization system was also used to assign delivery schedules and it achieved a loaded mileage proportion of 66%. Schedules chosen using the optimization system tended to be more uniform in length and also to visit multiple loggers during any given day, as opposed to the human-assigned schedules which had higher disparity between the shortest and longest daily schedules, and which tended to send trucks to only a single logger. The feasibility of the optimal solutions was not evaluated directly, but the routes tended to be replicated among trucks and trucks tended to visit multiple loggers more often than in observed schedules, both of which were felt to be characteristics of solutions that could be practically implemented. It was concluded that the optimization system could assist dispatchers in assigning schedules that were likely to be both feasible and shorter in overall length.

Literature Cited

1. Mendell, B.C.; Haber, J.A.; Sydor, T. 2006. Evaluating the potential for shared log truck resources in middle Georgia. Southern Journal of Applied Forestry. 30(2):86-91.

2. Murphy, G. 2003. Reducing trucks on the road through optimal route scheduling and shared log transport services. Southern Journal of Applied Forestry. 27(3):198-205.

3. Shen, Z.; Sessions, J. 1989. Log truck scheduling by network programming. Forest Products Journal. 39(10):47-50.

4. Taillard, E.; Badeau, P.; Gendreau, M.; Guertin, F.; Potvin, J.-Y. 1997. A tabu search heuristic for the vehicle routing problem with soft time windows. Transportation Science. 31(2):170-186.

5. Weintraub, A.; Epstein, R.; Morales, R.; Seron, J.; Traverso, P. 1996. A truck scheduling system improves efficiency in the forest industries. Interfaces. 26(4):1-12.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Methods and costs of skidder and truck stream crossings in Virginia

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Abstract

Two major concerns for logging contractors regarding stream crossings, involve the potential hazards to water quality and the costs associated with installation and closure of the crossing. Several research projects have revealed differences in water quality problems caused by different types of crossings. Crossings such as bridges, culverts, and fords are some of the major stream crossings that are installed within Virginia. The goal of this study was to survey Virginia logging contractors and gain insight into the types of stream crossings they have installed during the past year and the estimated total cost of the crossing. A survey was conducted consisting of 70 Virginia logging contractors randomly recruited from the Virginia Department of Forestry contact information database. Logging contractors were surveyed by phone and respondents were categorized by the three physiographic regions of Virginia with responses from 25 logging contractors in both the Coastal Plain and Piedmont and 20 logging contractors from the Mountians. The survey revealed that skidder stream crossings are more prevalent than truck crossings in all regions and that portable bridges are the dominant stream crossing for the Coastal Plain and Piedmont. In the Mountains, culverts are the crossing of choice. Overall cost of the structures follow the pattern of steel bridges > wooden bridges > culverts > fords. Fords and reinforced fords were seldom used.

Introduction

The installation and maintenance of stream crossings is often one of the most expensive forest best management practices (BMPs) to implement (Shaffer et al. 1998, Aust et al. 2003, O'Neal et al. 2006). However, the expense is typically justified because stream crossings and associated approaches have the potential to be one of the largest sources of sediment from forest operations (Taylor et al. 1999a, Carroll et al. 2008). Two of the largest expenses associated with stream crossings can be construction and maintenance. Aust et al. (2003) found temporary crossings, after installation, to range from $507 for a culvert crossing to $4,320 for a crossing using a portable stress laminated cant bridge. These crossings can be a large expense for logging contractors however they are necessary as the 2007-2008 assessment of BMP implementation by the Virginia Department of Forestry (VDOF) projected that stream crossings were installed on 81.4% of harvested sites in Virginia (Virginia Department of Forestry 2008).

Carroll (2008) found the major use of culvert and ford crossings to be on permanent roads. However, this study revealed that portable bridges had fewer water quality problems downstream of the crossings associated with water quality and erosion than culvert and ford crossings. Fewer water quality problems were associated with the ability to install these portable crossings without major bank or stream modification.

A study by Taylor et al. (1999b) found that the use of portable wooden bridges may help loggers to decrease sediment inputs into streams that occur with crossings such as fords and culverts. It was also found by Taylor et al. (1999b) that these crossings maybe only cost approximately $325 over its lifespan if it were used at 50 different sites. This was assumed using a ten year life expectancy for the portable bridges.

Taylor et al. (1999a) noted that stream crossings are generally accepted as the most critical location for sediment to enter a stream. Two typical sources of sediment are the crossing structure itself and the road approaches to the crossing. Taylor et al. (1999a) also found an overall lack of literature regarding long-term stream crossing impacts. Most studies are short-term and focused mainly on crossing installation.

In a stream crossing study by Lane and Sheridan (2002) conducted in Victoria, Australia, the principal sediment sources were found to be the roads with increased sedimentation during the construction period. Suspended sediment and turbidity levels increased downstream of a newly constructed stream crossing and increases were also seen in amount of bedload material. Rainfall was a controlling agent to the amount of sediment introduced into the stream. The study found that protection from concentrated flow along with the use of gravel at crossings could help protect against increased sedimentation of streams.

The objectives of this study were to survey Virginia logging contractors in order to gain insight into: 1) the types of stream crossings they have installed during the past year, and 2) the total estimated cost of the crossings (including purchase and installation costs).

Methods

A survey was designed targeting full time logging contractors within the state of Virginia during the fall of 2009. The telephone survey was comprised of ten multi-part questions regarding types of stream crossings used for trucks and skidders, and the costs associated with purchasing and installing these crossings. The equipment used to install the stream crossings was also evaluated in the survey.

The VDOF contact information database of over 800 logging contractors was used to randomly select the 70 logging contractors surveyed for this study. All logging contractors were assigned to a physiographic region based on business address: Mountains, Piedmont, or Coastal Plain

(Figure 1). The contractors were then assigned a number which was entered into a database to randomly select companies and generate a random caller list within each region. Contractors who reported they were not full-time contractors were excluded from the survey. If a contractor could not be contacted we continued to the next random name. A hard copy of the questionnaire was used during the phone survey to record the data obtained from the participants. All participants verbally agreed to participate in the study and were given the option to opt out at any point during the survey. Of the 70 respondents, 20 were from the Mountains region, 25 were from the Piedmont region, and 25 were from the Coastal Plain region.

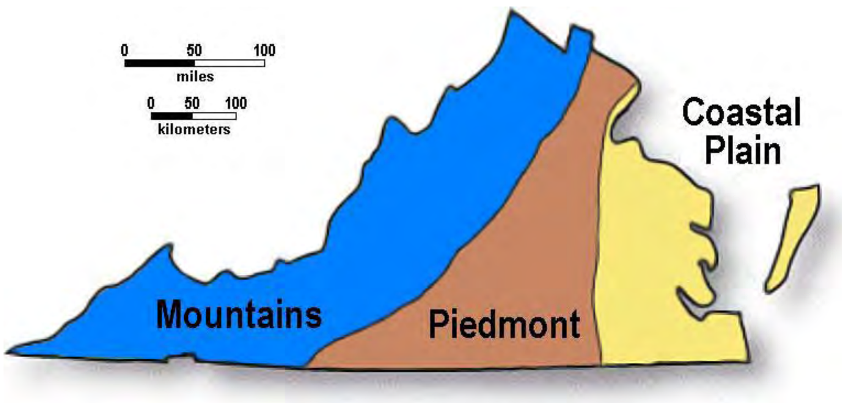

Figure 1. State of Virginia by physiographic region. Courtesy of Hodkinson et al. (2009).

Results and Discussion

Stream Crossing Usage

Results of the survey generally reflect the differences in contractors, terrain, availability of crossing manufacturers and materials, and the localized conditions between the regions. Overall results indicate that logging contractors use a greater number of stream crossings for skidders than for log trucks in all regions of Virginia (Table 1). While the number of crossings used by each contractor in the past year was not obtained by this survey, it appears that logging contractors avoid using stream crossings on haul roads if possible. An average of 47% of all contractors surveyed used stream crossings for trucking while 95% of these contractors used crossings for skidding (Table 1). These findings may reflect the more permanent nature of haul roads where crossings already exist. Another interpretation of these data may be that the installation of truck stream crossings is limited due to the fact that their constructions can be cost prohibitive.

Table 1. Total number of logging contractors by physiographic region that used either a truck crossing or skidder crossing during the previous year.

Stream Crossing Type	Coastal Plain (n=25)	Piedmont (n=25)	Mountains (n=20)
Truck Crossings	8 – (32%)	12 – (48%)	12 – (60%)
Skidder Crossings	25 – (100%)	24 – (96%)	18 – (90%)

Stream crossings used by trucks are mainly culvert crossings in all three regions with the Piedmont region having an equal number of loggers using both culverts and steel bridges (20%)

for truck crossings (Table 2). The Mountain region had the highest percentage of contractors who used at least one stream crossing for trucking in the last year with 60% (Table 1). The Piedmont and Coastal Plain contractors followed with 48% and 32% of contractors using crossings on haul roads, respectively (Table 1). This is possibly due to the increased drainage density exhibited in the Mountains of the state that decreases towards the Piedmont and again towards the Coastal Plain. Also, the forest road network is more extensive in the Coastal Plain and Piedmont regions.

Table 2. Percentage of loggers by physiographic region that have used a particular type of stream crossing for truck or skidder crossings during the previous year.

		Mountains (n=20)	Piedmont (n=25)	Coastal Plain (n=25)
Truck Crossings	**Ford**	10%	8%	0%
	Culvert	40%	20%	16%
	Wooden Bridge	10%	12%	12%
	Steel Bridge	0%	20%	8%
Skidder Crossings	**Ford**	0%	4%	4%
	Culvert	70%	20%	16%
	Wooden Bridge	40%	48%	64%
	Steel Bridge	10%	56%	24%

Fords were used only by four of the 70 contractors surveyed for truck crossings, two from the Piedmont and two from the Mountains. In the Piedmont and Coastal Plain, the use of steel and wooden bridges as stream crossings for trucks was similar to that of the use of culverts for crossings. Although these portable crossings were originally designed for skidding use because of mobility and ease of installation, they are utilized by loggers around the state for a variety of crossing situations.

Skidder crossings differ by region with steel and wooden bridges being preferred in the Coastal Plain and Piedmont and culvert crossings being preferred in the Mountains (Table 2). Wooden bridges in the Coastal Plain are the crossing of choice (64%). However steel bridges are incorporated by more contractors (56%) in the Piedmont and the use of wooden bridges is still high at 48% (Table 2). Steel bridges are only used by 24% of loggers in the Coastal Plain. The difference in steel or wooden crossing usage may be a reflection of availability; wooden bridges can be acquired from the Richmond area in the Coastal Plain and lower Piedmont while steel bridges are available through manufacturers in the central Piedmont. Culvert crossings are used by 70% of loggers in the Mountain region (Table 2). Wooden and steel bridges are used less often by Mountains contractors, 40% and 10% respectively (Table 2). Fords were again not a prevalent skidder crossing type in any of the regions.

The use of culverts dominates in the Mountain region of the state but portable wooden and steel bridges have potential benefits for stream crossings in the region. Portable bridges are reusable for both trucks and skidding, and they can reduce the impact on stream quality. These bridges allow for no modification of stream beds and typically do not directly introduce sediment into the stream. They are also easy to install due to their ability to be handled with the skidders on site.

Costs

Cost estimates for each crossing type were gathered and averaged for each region of Virginia (Table 3). Costs were broken into both material or purchase price and the cost of installation. Due to usage differences, price estimates for each crossing type are not available for every region. In general, steel bridges have the most expensive initial purchase cost with an average estimated cost of $10,563 in the Piedmont and $8,875 in the Coastal Plain. Total costs of steel bridges do not take into account the ability to use these crossings multiple times. While the data did not capture the life expectancy of these bridges, if we assume they can be used for a minimum of 10 crossings their price is generally equal to that of installing a new culvert at each of these crossings.

Table 3. Costs associated with purchasing and installing stream crossings in the three physiographic regions of Virginia.

	Crossing Type	Material Cost	Installation Cost	Total Cost
Coastal Plain (n=25)	Ford	---	---	---
	Culvert	$906	$550	$1,456
	Wooden Bridge	$2,363	$354	$2,717
	Steel Bridge	$8,875	$193	$9,068
Piedmont (n=25)	Ford	---	---	---
	Culvert	$1,186	$400	$1,586
	Wooden Bridge	$2,627	$230	$2,857
	Steel Bridge	$10,563	$683	$11,246
Mountains (n=20)	Ford	$900	$75	$975
	Culvert	$527	$233	$760
	Wooden Bridge	$2,460	$108	$2,568
	Steel Bridge	---	---	---

Wooden bridges cost an average price of just under $2,500 between all three regions. Installation of wooden bridges tends to be lower than the cost of steel bridges but these costs are generally similar. Wooden bridges range from $108 to install in the Mountain to $354 to install in the Coastal Plain. While wooden bridges are less expensive than their steel counterparts they do not tend to last as long. However, using the same assumption regarding reuse, their costs will generally be comparable to culverts over time if properly maintained.

Culverts are the least expensive crossing type in the Mountains with an average cost for pipe equaling $527. The average cost of installation equals $233 for a total cost per culvert to be $760. In the Piedmont and Coastal Plain the average cost of purchasing a culvert is $1,186 and $906, respectively. These costs differ due to location and distance to manufacturers. Cost difference may also reflect regional differences in stream size. Installation of culverts is also higher in the Piedmont and Coastal Plain at $400 and $550, respectively. Average installation costs for culverts are similar to those found by Shaffer et al. (1998) after accounting for inflation. Many different materials can be used for culverts such as steel pipe or gas pipeline which is of high availability and low cost in the Mountain region. These different materials have differing life expectancies, and some contractors reuse culverts for more than one temporary crossing however they do not tend to last as long as bridges.

Summary and Conclusions

Of the total number of loggers surveyed, 26% have not used stream crossings within the last year (Table 1). Of the 74% that have used stream crossings, culverts and wooden bridges were the most common (Table 2). Both fords and reinforced fords were rarely used through all regions of the state. Use of portable bridges, both steel and wooden, varied from very few contractors in the Mountains to being very common in the Piedmont and Coastal Plain. Overall, crossings were used more for skidder traffic than for truck traffic.

The overall average cost to purchase a culvert is $873 (Table 3). This cost reflects the average diameter and length of the culverts used throughout the three regions of Virginia. The overall average cost of a wooden bridge is approximately $2,483 and the overall average initial cost of a steel bridge is $9,719 (Table 3). Average installation costs range from $230 for a culvert and $438 for a steel bridge, but these costs vary widely by region.

Previous studies have indicated that portable bridges have both operational and environmental advantages over structures that require in stream modifications such as fords or culverts (Carroll 2008). It appears that logging contractors in the Coastal Plain and Piedmont have embraced portable bridges, while contractors in the Mountain region are less enthusiastic about their use. The VDOF has developed a cost share program to help logging contractors acquire portable bridges and these types of efforts may increase acceptance. Also, there are relatively few manufacturers of portable bridges in the Mountain region which may partially explain their infrequent use.

Acknowledgements

The authors wish to thank the 70 logging contractors from across the state of Virginia who participated in this survey along with the Virginia Department of Forestry for their logistical support. This study was supported partially by the Virginia Tech Forest Operations and Business Research Cooperative.

Literature Cited

Aust, W. M, J.M.R. Visser, T. Gallagher, T. Roberts, and M. Poirot. 2003. Cost of six different stream crossing options in the Appalachian area. *South. J. Appl. For*. 27(1): 66-70.

Carroll, M. 2008. *The effects of stream crossings and associated road approaches on water quality in the Virginia Piedmont*. M.S. Thesis. Department of Forestry. Virginia Tech, Blacksburg, Va.

Carroll, M.B, W.M. Aust, C.A. Dolloff, and R.M. Shaffer. 2008. The Effects of Stream Crossings Approaches on Water Quality in the Virginia Piedmont. In Proc. of *Council on Forest Engineering*. Charleston, SC. June 26-27, 2008.

Hodkinson, B. P., R. C. Harris, and M. A. Case. 2009. A Checklist of Virginia Lichens. *Evansia* 26(2): 64-88 http://www.duke.edu/~bph8/VirginiaLichens/checklist.html. [updated: 05 January 2010].

Lane, P.N.J., and G.J. Sheridan. 2002. Impact of an unsealed forest road stream crossing: water quality sediment sources. *Hydrological Processes*. 16: 2599-2612.

O'Neal, B.S., W.A. Lakel, W.M. Aust, and R.M. Visser. 2006. AVLO: A simplified cost analysis approach for estimating construction costs for forest roads. In Proc. of *Council on Forest Engineering*, Coeur d'Alene, ID. 4 p.

Shaffer, R.M, H.L. Haney Jr., E.G. Worrell, W.M. Aust. 1998. Forestry BMP Implementation Costs for Virginia. *For. Prod. J*., 48(9): 27-29

Taylor, S.E., R.B. Rummer, K.H. Yoo, R.H. Welch, and J.D. Thompson. 1999a. What we know and don't know about water quality at stream crossings. *J. For*. 101(8): 12-17.

Taylor, S.E., M.A. Ritter, J.M. Franklin, P.A. Morgan, K.P. Keliher. 1999b. Portable Timber Bridge Systems for Forest Roads. In Proc. of *International Council of Forest Engineering.* Edinburgh University, Edinburgh, Scotland. June 28-30, 1999.

Virginia Department of Forestry. 2008. *Silvicultural Best Management Practices Implementation Monitoring for Virginia: 2007-2008*. Virginia Department of Forestry, Charlottesville, VA. 8 p.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Project Summary:

Application of a Trailer-Mounted Slash Bundler for Southern Logging

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Introduction

The John Deere bundler was originally designed to collect material behind a cut-to-length (CTL) operation, where the biomass feedstock is distributed across the harvested site. While the occurrence of a CTL operation is common in Europe, it is rarely used in the southern United States. Southern logging typically involves a tree-length operation, where the whole tree is skidded to the landing for processing. Therefore, the residual portions of the tree (primarily limbs and tops), which can be used as a biomass feedstock, are already located on the landing and available for the market.

Efficiently transporting this material requires some kind of densification practice. Some loggers are using small residue chippers for this process. However, some markets would prefer the biomass in larger form to facilitate handling and drying. Chippers also have high variable costs for fuel and knives. Bundling offers an alternative to chipping, but a mobile machine like the John Deere 1490E is an expensive option to consider.

The idea of mounting the bundling unit to a stationary trailer was conceived to reduce the capital cost of the machine and allow easier integration into a southern logging operation. A meeting was held in Auburn, Alabama in June, 2008 to develop the project. Auburn University was the lead on the project, with funding from the USDA Forest Service and in-kind support from John Deere in the form of the bundler and knuckle-boom loader. Cutting Systems, Inc. (CSI) also participated by donating one of their motorized trailers for use during the project.

Machine Build

To facilitate the schedule of the project, the bundler was mounted on a motorized trailer provided by Cutting Systems, Inc. (CSI). CSI's rugged trailer design, out riggers, and grapple loop made it ideal for in-woods use. The self-contained trailer features a 102 hp, John Deere diesel engine. The fixed displacement pump was replaced with an Oilgear, model PVM098, variable displacement pump.

The bundler's mounting configuration was modeled after the newest design of the John Deere 1490. Three, one inch steel plates were welded at intervals on each side of the trailer directly over the axle. Two, four inch schedule 40 steel tubes were welded onto the plates for mounting. Some additional bracing was welded into place for added security, and the B-380's mounting pedestal was then lifted into place. After fastening the pedestal to the rail system, the bundler was mounted securely atop the trailer.

Figure 1. Trailer mounted bundler prototype.

The trailer was then plumbed and the reservoir was filled with hydraulic fluid. To satisfy the higher voltage required by the bundler, a small amplifier was installed to convert the 12 volt battery power to 24 volts. While the original plan was to have a remote control system, there were too many challenges with the software system. As a result, a 75 foot extension was attached to the wiring harness to ensure operator safety during testing.

Field Testing

Field testing was performed on five different sites to evaluate the machine. The sites were located in east central Alabama and north central Florida. Each contained different stand conditions. The initial four sites were test and demo sites with the fifth being the production study site.

Auburn Test Site

Tim West, Mike Schmidt, and Bryon Neumann were on site to assist in the initial testing which was performed on Auburn University property. The source for the whole tree material used for bundling was an 18 year old loblolly pine plantation. The trees averaged 50 feet tall and 6 inches at breast height (dbh). Bundling took place for 1 ½ days; functionality was normal, and the machine performed well. There were no significant problems bundling the material. While no formal data was recorded, processing time for an eight foot bundle ranged between 90 and 100 seconds.

Figure 2. Initial testing of the bundler in Auburn, Alabama.

Midway Test Site

The Midway, Alabama site contained mature pine timber with a significant amount of mature bottomland hardwoods. The bundler and loader were setup in close proximity to the active logging deck. The cooperating logger operated a two loader, two skidder, and one feller-buncher system. Skidder operators used a gate to delimb the trees before bringing them to the deck. Due to the large timber and use of the gate, the material was not ideal for bundling. The material contained a large proportion of 6 – 12" diameter woody stems with very little foliage. Bundles broke apart due to the lack of outward pressure that small limbs and foliage provide.

The unit was proven capable of bundling smaller hardwood tops; however, mature hardwood tops with crooks and forks led to problematic bundling. After being compressed, one crooked limb was thrust upward and broke the bundle hold down bar. Several times the material would pinch the saw bar. This complication in severing the bundle led to a couple of bent saw bars. A visit by Brian Reimer of John Deere resulted in some changes to the software defaults that enhanced the bundling operation. The changes enabled the number of wraps, distance between wraps, and bundle length to be altered.

Although bundling is possible in the Midway conditions, it is not ideal. A harvesting system that would bypass the gate and delimb at the deck using a pull-through delimber would provide a better mix of material.

Figure 3. Bundling hardwood slash at the Midway test site.

Live Oak Demo

This demo was put together by the US Forest Service and Auburn University, and locally hosted by the North Central Florida and the Suwannee River RC&D Councils. More than 120 politicians, power company personnel, loggers and landowners attended the Live Oak, Florida demonstration which showed a slightly different application of the machine. The demo site was a recently clearcut stand that contained piled logging residue. The operation was set up adjacent to a large slash pile composed of mostly pine limbs and tops. Although the material had been sitting for weeks, the bundling operation processed the biomass with minimal problems.

Notasulga Test Site and Demo

The Notasulga, Alabama site consisted of two significantly different stand conditions. The operation piggybacked a logger that was clearcutting a 23 year old loblolly stand and thinning a younger loblolly pine plantation on the same tract. The cooperating logger, Caldwell Logging, utilized one loader, two skidders, and a single feller-buncher. The bundling operation was set up in close proximity to the active logging deck. Skidders transported slash from the loader's pull-through delimber to the bundling operation. The operation did not use a gate to delimb the trees; consequently, both the clearcut, and thinning material compressed and bundled well.

Figure 4. Bundling operation in Notasulga, Alabama.

Bundling efficiency is greatly affected by the capabilities of the loader operator. An experienced operator from Caldwell Logging mastered the in-feed operation in a very short period of time. The operator went on to assist in the bundling demo which was attended by approximately 50 loggers, mill personnel, foresters, equipment dealers, and government personnel. Bundling went extremely well and the material mix was ideal.

Production Study

The Roanoke, Alabama site, a 90 acre clearcut, consisted of a large loblolly pine component with a small number of hardwood trees. Bundling productivity data was collected for one week on a 25 acre portion of the tract. The stand was inventoried prior to harvesting. In addition, work study data was collected on skidder performance to assess any changes in productivity. Time study data was collected on the bundling operation and delays were recorded for post processing.

Stand Conditions and Inventory

The gently sloping 25 acre stand was a naturally regenerated loblolly pine stand. It contained 121 tons per acre of total merchantable timber with the vast majority being pine sawtimber. The following volume table shows the breakdown by species and product class. Sixteen, 1/10th acre plots were measured to provide an estimate of standing inventory.

	Tons per Acre
Pine Sawtimber	86
Pine Pulpwood	22
Hardwood Sawtimber	2
Hardwood Pulpwood	11
Residue Available	32.5
Residue Harvestable	22.75

Table 1. Roanoke Site Stand Inventory

The residue availability estimates and merchantable weights are based on *Georgia Forest Research Paper 60 and 79.*

Logging System and Work Study

The tree-length logging operation, Sanders Logging, consisted of two loaders, two skidders, and one feller-buncher. Typically, the feller-buncher would maintain a one half to a full day buffer ahead of the skidders. Before bundling commenced, skidders would delimb the trees using a gate on approach to the logging deck. By delimbing in this manner, the skidders would have to clean slash from both the gate and the pull through delimbers on the deck.

During bundling operations, delimbing was performed strictly on the deck with pull through delimbers. This alteration in the operation produced a higher concentration of slash at the deck and potentially affected the skidders' productivity. In order to quantify the change in productivity caused by bundling and the adjustments in the delimbing process, a work study was performed on the skidders.

The study's work sampling noted the skidder's operation every 4 minutes. Four days of skidder data was collected while the operation was using the gate to delimb trees. On average, gate delimbing consumed about 7% of total productive skidding time. The pre-bundler data also showed that slash movement away from the deck consumed an average of 11% of total productive time. On the other hand, during the bundling operation when gate delimbing was not utilized, slash movement only consumed approximately 7% of total productive skidding time. This indicates that bundling should not interfere with skidder productivity and may even enhance it.

Bundler Productivity

Bundler productivity was collected over a one week timeframe. The number of loader turns and saw bar cuts were collected as independent variables for cycle time equations. Delays were noted for data analysis and machine evaluation. Cycles were timed from the severing of one bundle until the severing of the next.

Measured production levels showed the prototype unit was capable of producing an average of 33.4 eight foot bundles per hour (15.9 tons/hr) with no delays. Accounting for minor operational delays that were observed during the production study (such as extra saw cuts and feeding delays), the average production for the bundling operation was 30.8 eight foot bundles per hour (14.6 tons/hr). A string repair occurred every 2.6 hours of run time with an average repair time of 12 minutes. To maintain proper functionality, saw chains were changed every 2.2 hours with a standard repair time of 14 minutes.

A limited number of 12 foot bundles were produced during the study. Without any delay considerations, 25.5 twelve foot bundles per hour (17.2 tons/hr) were produced. Minor delays slightly decreased production to 24.2 bundles per hour (16.4 tons/hr). String and saw chain repair delays were estimated to be equivalent to those that occurred during 8 foot bundle production.

Of the two lengths, the 12 foot bundles proved to be the most conducive to a production bundling operation in the study conditions. Twelve foot bundles generated between 5 and 10 percent more tons per hour in production. Twelve foot bundles also trailered better for safe transportation. Based on our observed average bundle weight, three bunks of twelve foot bundles at fifty percent moisture content would weigh approximately 27 tons.

Economic Analysis

Capital investment, variable costs, and revenue streams are uncertain with this prototype. Reasonable estimates have been applied to a *DISCOUNTED AFTER-TAX CASH FLOW COST ANALYSIS SPREADSHEET,* developed by Dr. Robert Tufts of Auburn University, to determine some of the economics surrounding a trailer mounted bundling operation.

Two different options were considered for the loader cost analysis. An older, used loader was evaluated with a lower initial price, but higher fuel consumption and maintenance costs. The second option was a new, small loader with lower fuel consumption and maintenance costs. The two options produced similar costs and purchasing a small new loader for bundling seemed the most logical decision.

A 75% utilization rate (1500 PMH/2000 SMH/yr) is assumed for both the loader and the bundler. Fuel consumption for both the loader and the bundler averaged 2.5 gallons per hour. For analysis purposes, we assumed 3 gallons per hour, a fuel cost of $2.50/gal, and a lube cost of $2.50/ hr (total fuel and lube was $10/PMH). Maintenance and repair costs for the bundler were based on conclusions from the field study. The operation consumed 1 roll of twine per 25 eight foot bundles. At a cost of $23 per roll, twine costs equated to roughly $2 per ton. Chains for the chainsaw consumed another large portion of the maintenance costs. Assuming 5 sharpenings per chain, and an effective chain cutting life of ½ day, chain costs total approximately $12,500 per year or $0.60 per ton. Allowing for some repair costs, total maintenance and repair was estimated to be $50/PMH. The tables on the following pages show the economic analyses of eight, and twelve foot bundling operations.

The annual equivalent cost (AEC) is the cost per year to own and operate the piece of machinery over its entire lifespan. Assuming a life span of four years, the eight foot bundling operation cost estimates totaled $12.85 per ton to produce bundles. Twelve foot bundles totaled $11.25 per ton to operate the loader and trailer mounted bundling unit. By adding $6 per ton for trucking, $2 per ton profit for the logger, and $1 per ton for stumpage to the land owner, bundles could potentially be delivered to a facility within 50 miles for approximately $20-$22 per ton.

Because the purchase price of the trailer mounted bundler is unknown, sensitivity analysis was performed at $200,000, $250,000, and $300,000. $7.44, $8.08, and $8.71 were the respective cost per ton of eight foot bundling. Twelve foot bundling cost per ton was $6.51, $7.07, and $7.62 respectively. An increase in the purchase price by $50,000 would constitute a 50-60 cent increase in cost per ton for bundling.

Loader Analysis (8 ft bundle operation)					
Purchase price	$150,000			Discount rate	6.00%
Trade-in	$0			Finance APR	10.00%
BV of trade-in	$0			Marginal tax rate	15.00%
Down payment	$0			Amount financed	$150,000
Number of payments	48			Monthly payment	$3,804
Expense Option	$0			Adjusted basis	$150,000
Hours per day	8.00			Expected life, years	4
Days per year	225			Residual value end of life	40.00%
Fuel & Lube	$10.00			Inflate F&L	5.00%
Maint & Repair	$10.00			Inflate M&R	15.00%
Labor rate	$15.00			Inflate labor	5.00%
Fringe benefit %	30.00%			Utilization	75.00%
Insurance & taxes	4.00%			Production (tons/PMH)	14.00
AEC		($102,557)	($98,737)	($95,276)	($92,245)
Cost per ton		($5.43)	($5.22)	($5.04)	($4.88)
		Year 1	Year 2	Year 3	Year 4
Salvage value		114,000	87,000	69,000	60,000
ACRS Dep		30,000	48,000	28,800	17,280
Book value		120,000	72,000	43,200	25,920
Fuel & Lube		15,000	15,750	16,538	17,364
Repair & Maint.		15,000	17,250	19,838	22,813
Labor		35,100	36,855	38,698	40,633
Insurance		6,000	4,560	3,480	2,760
Total Expenses		71,100	74,415	78,553	83,570

Table 2. Loader Economics (8 ft bundles)

Bundler Analysis (8 ft bundle operation)				
Purchase price	$250,000		Discount rate	6.00%
Trade-in	$0		Finance APR	10.00%
BV of trade-in	$0		Marginal tax rate	15.00%
Down payment	$0		Amount financed	$250,000
Number of payments	48		Monthly payment	$6,341
Expense Option	$0		Adjusted basis	$250,000
Hours per day	8.00		Expected life, years	4
Days per year	225		Residual value end of life	20.00%
Fuel & Lube	$10.00		Inflate F&L	5.00%
Maint & Repair	$50.00		Inflate M&R	15.00%
Labor rate	$0.00		Inflate labor	5.00%
Fringe benefit %	30.00%		Utilization	75.00%
Insurance & taxes	4.00%		Production (tons/PMH)	14.00

AEC		($172,203)	($164,630)	($158,066)	($152,646)
Cost per ton		($9.11)	($8.71)	($8.36)	($8.08)
		Year 1	Year 2	Year 3	Year 4
Salvage value		170,000	110,000	70,000	50,000
ACRS Dep		50,000	80,000	48,000	28,800
Book value		200,000	120,000	72,000	43,200
Fuel & Lube		15,000	15,750	16,538	17,364
Repair & Maint.		75,000	86,250	99,188	114,066
Labor		0	0	0	0
Insurance		10,000	6,800	4,400	2,800
Total Expenses		100,000	108,800	120,125	134,230

Table 3. Bundler Economics (8 ft bundles)

Loader Analysis (12 ft bundle operation)				
Purchase price	$150,000		Discount rate	6.00%
Trade-in	$0		Finance APR	10.00%
BV of trade-in	$0		Marginal tax rate	15.00%
Down payment	$0		Amount financed	$150,000
Number of payments	48		Monthly payment	$3,804
Expense Option	$0		Adjusted basis	$150,000
Hours per day	8.00		Expected life, years	4
Days per year	225		Residual value end of life	40.00%
Fuel & Lube	$10.00		Inflate F&L	5.00%
Maint & Repair	$10.00		Inflate M&R	15.00%
Labor rate	$15.00		Inflate labor	5.00%
Fringe benefit %	30.00%		Utilization	75.00%
Insurance & taxes	4.00%		Production (tons/PMH)	16.00

AEC		($102,557)	($98,737)	($95,276)	($92,245)
Cost per ton		($4.75)	($4.57)	($4.41)	($4.27)
		Year 1	Year 2	Year 3	Year 4
Salvage value		114,000	87,000	69,000	60,000
ACRS Dep		30,000	48,000	28,800	17,280
Book value		120,000	72,000	43,200	25,920
Fuel & Lube		15,000	15,750	16,538	17,364
Repair & Maint.		15,000	17,250	19,838	22,813
Labor		35,100	36,855	38,698	40,633
Insurance		6,000	4,560	3,480	2,760
Total Expenses		71,100	74,415	78,553	83,570

Table 4. Loader Economics (12 ft bundles)

Bundler Analysis (12 ft bundle operation)				
Purchase price	$250,000		Discount rate	6.00%
Trade-in	$0		Finance APR	10.00%
BV of trade-in	$0		Marginal tax rate	15.00%
Down payment	$0		Amount financed	$250,000
Number of payments	48		Monthly payment	$6,341
Expense Option	$0		Adjusted basis	$250,000
Hours per day	8.00		Expected life, years	4
Days per year	225		Residual value end of life	20.00%
Fuel & Lube	$10.00		Inflate F&L	5.00%
Maint & Repair	$50.00		Inflate M&R	15.00%
Labor rate	$0.00		Inflate labor	5.00%
Fringe benefit %	30.00%		Utilization	75.00%
Insurance & taxes	4.00%		Production (tons/PMH)	16.00

AEC		($172,203)	($164,630)	($158,066)	($152,646)
Cost per ton		($7.97)	($7.62)	($7.32)	($7.07)
		Year 1	Year 2	Year 3	Year 4
Salvage value		170,000	110,000	70,000	50,000
ACRS Dep		50,000	80,000	48,000	28,800
Book value		200,000	120,000	72,000	43,200
Fuel & Lube		15,000	15,750	16,538	17,364
Repair & Maint.		75,000	86,250	99,188	114,066
Labor		0	0	0	0
Insurance		10,000	6,800	4,400	2,800
Total Expenses		100,000	108,800	120,125	134,230

Table 5. Bundler Economics (12 ft bundle)

Recommended Deck Configuration

When the project was initially discussed, we considered integrating the trailer mounted bundler directly into a two loader system. After running the operation in the field, our initial presumptions have been altered. With the slash volumes we encountered during field tests, a separate loader needs to be allocated specifically for bundling. In this production study, we found the ratio of slash loads to roundwood loads to be around 1:5. For a 15 loads a day roundwood operation, producing 25-30 bundles/hr, an operator would be bundling for 6-7 hours per day.

The bundling operation should be within close proximity to the active logging deck in an effort to not affect skidder production during slash delivery. Forest residues should be deposited at the rear of the loader. Slash should be fed into the bundler from left to right so that the boom does not alter the operator's line of sight. Using set-out trucking and loading finished bundles directly onto a trailer would limit handling and increase production.

The figure below is the most efficient bundling deck configuration found during the trial period. The bundler position enables smooth feeding, and extraction of bundles. Positioning the loader in this fashion allows the operator effective reach of all necessary elements.

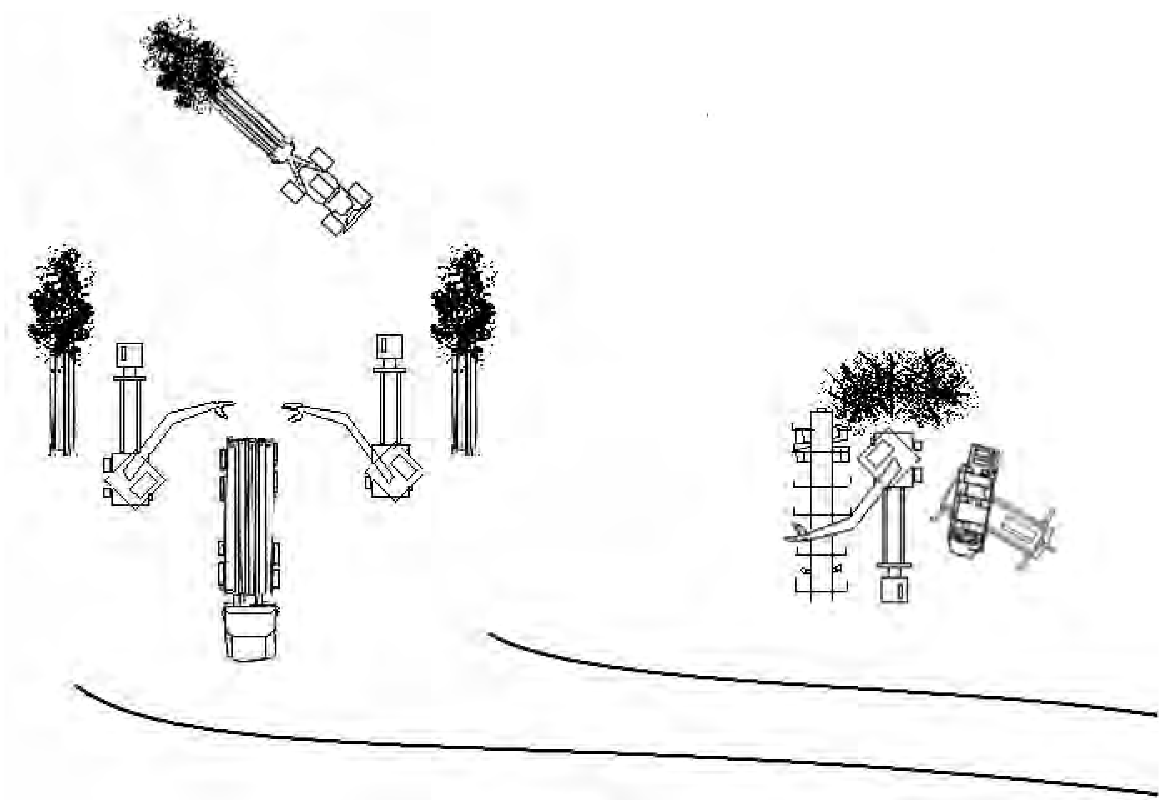

Figure 5. Optimal Deck Configuration

Recommended Improvements to the Prototype Trailer-Mounted John Deere Slash Bundler Unit

After conversations with Mike Schmidt, Tim West and others, the following suggestions are experience-based propositions that will make the trailer mounted slash bundler a more marketable addition to southern logging systems.

1) ***Rotation configuration***
   The piston driven rotation configuration within the turnstile needs to be redesigned. A gear based design seems much more effective. The middle "dead zone", when the piston is fully extended, renders the rotation function useless. When not in use, the unit occasionally drifts around and could potentially cause damage to the loader or bundler.
2) ***Cutting configuration***
   In our studies, the cut off saw was to be one of the biggest sources of operational delays. The chainsaw hangs up without completely severing the bundles. At times, the saw bar will cycle down 2-5 times before cutting through the bundle entirely. Chain life is also an issue. Chains seem to have an effective cutting life of 2-4 hours. The chain will cut for a longer period of time; however, the saw delays become more prevalent. Some of these problems could possibly be reduced by issuing pressure recommendations for the hold down arm and saw bar depending upon bundle length.
3) ***In-feed configuration***
   For the most part, feeding the material into the machine was not a huge concern. After a short period of time, feeding slash comes naturally to a loader operator. A chain in-feed tray on the bottom seems like a viable option to aid the forward movement of the slash. Extending the vertical rollers would enable the bundler to grasp material more effectively.
4) ***Protection for the hold down bar***
   The hold down bar is a must; however, on multiple occasions a crooked or forked stem has maneuvered itself into a position to bend the bar. These incidents, although sparse in number, are extremely costly both monetarily and in productivity. Extension of the protective steel guide is recommended in order to the steer the bundles away from this critical part.

Figure 6. Location of the hold down bar protection.

5) ***Overall heightened protection***

   A) The valve bank is protected by a piece of sheet metal. The cover should be reinforced and have some type of metal stops instead of resting on hydraulic hoses at the bottom.

   B) With such an extensive hydraulic system, the numerous hoses are inevitable. Hoses should be more protected in various areas.

   C) Encase or extend protection of exposed hydraulic fittings. Both compactor 2 and 3 have some exposed fittings that could be covered by simply extending existing protective pieces.

6) ***Remote control***

   Remote control is crucial for this unit's success. A lone loader operator must be able to feed and bundle to make bundling safe and economical. The remote must be able to operate all the functions; however, remote operation of the display and bundle configuration options is not required.

7) ***Display and bundle length***

   The unit's display needs to be in English units for ease of operation. During eight foot bundling operation, bundle length varied from 254 cm to 272 cm. Length variation could cause problems when hauling bundles crossways on the trailer.

Trailer modifications

Although the CSI trailer was adequate, it was utilized because of the project's timeline. A purpose built trailer should be constructed with the following suggestions in mind.

8) ***Power requirements***

The 102 hp diesel engine used to power the unit was adequate. The only power issue with the tested unit existed in low temperatures when the hydraulic oil was more viscous than normal. This problem could be minimized by installing a pre-heater for the hydraulic oil or by running a lower viscosity oil.

9) ***Height of the unit***

Height is a valid concern for a trailer mounted unit. The prototype trailer mounted unit is 13 feet, 6 inches tall. The production unit must have a lower center of gravity to ensure safe transportation. Lowering the unit would also give the operator a better line of sight during loading. On the other hand, in order to conserve bundling integrity, the unit must be high enough that bundles can freely drop after being severed. Examination of the proto-type reveals many opportunities to reduce the height, including different mounting configurations as well as lowering the height of the trailer's metal housing.

10) ***Axle(s)***

The current unit does not meet DOT standards for transport on a single axle trailer. The bundler, including the mounting configuration, weighs approximately 9 tons. The CSI trailer weighs nearly 6 tons. A tandem axle trailer setup would not only legally bear the weight, it would also aid in the stability during travel on the highway and on rough in-woods roads.

11) ***Maintenance***

In order to ensure the safety of workers, a maintenance deck should be built into the production model. Climbing on oily, slick surfaces is a safety hazard. A trailer mounted collapsible or folding platform would aid in the ease of maintenance for this machine.

12) ***Outriggers***

Outriggers assist in the leveling of the unit on uneven surfaces. The production model trailer should feature outriggers because the added stability aids in safe and efficient bundling.

13) ***Towing***

The trailer and tongue weight of the trailer mounted bundler should be within the towing capabilities of a heavy duty service truck for transportation. The pintle hook setup should protrude further from the grapple loop to ensure a more conducive towing configuration. The grapple loop is essential for in-woods transportation by skidders.

14) ***Additional transport considerations***

A tie down system should be adapted to the trailer in order to ensure the bundler does not rotate in transit.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Torrefaction? What's that?

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Fueling the Future: 2010 Council on Forest Engineering Annual Meeting
June 6-9, 2010; Auburn, Alabama

Abstract

Torrefaction is a thermo-chemical process that reduces the moisture content of wood and transforms it into a brittle, char-type material. The thermo-chemical process can reduce the mass of wood by 20-30% resulting in a denser, higher-valued product that can be transported more economically than traditional wood chips. Through torrefaction, wood may retain 90% of the energy value. This energy dense end-product can be used as a coal replacement or co-fired/co-milled with coal in electricity generating power plants. Torrefied wood can be used as a soil amendment, for backyard grilling, residential heating, or as a feedstock in gasification processes. This paper is a literature synthesis that will present (1) the torrefaction process, (2) current developments in commercial torrefaction equipment, (3) characteristics of and markets for torrefied wood, and (4) feedstock specifications for torrefaction.

Introduction

Woody biomass torrefaction is a process of heating biomass in a low-oxygen environment. There is some variation in the reported temperatures used in torrefaction. In existing literature, torrefaction ranges were found from 220 - 300ºC (428 - 572ºF). These temperatures are much lower than those often related to fast pyrolysis (400-600ºC) or gasification (900ºC or higher) (Table 1).

Wood properties undergo changes when processed at temperatures associated with torrefaction. Woody biomass consists of hemicelluloses, cellulose, lignins, and extractives. Torrefaction releases water and volatile organic compounds. Some of the lignin is devalitized and the remaining lignin is loosened. Hemicellulose is released and the remaining bio-char is a product of the torrefaction process. It is an intermediate product between wood and charcoal and has most of the advantages of both products.

Compared to the coal it replaces, biomass reduces sulfur dioxide (SO_2), nitrogen oxides (NOx), and net greenhouse gas emissions of CO_2 (Lipinski et al, 2002). Co-firing torrefied wood is more attractive than using raw biomass such as wood chips because the torrefied wood is friable and can be blended, pulverized and co-fired with coal. The capital and operating costs for separate biomass fuel feed and firing systems are avoided.

Table 1. Types of thermal decomposition processes in the absence of oxygen				
Process	**Conditions**	**Bio-oil**	**Char**	**Gas**
Fast pyrolysis	Moderate temperatures. Very short time	60-75%	10-15%	10-15%
Carbonization	Low temperatures. Very long time	30%	40%	30%
Gasification	High temperatures. Long time	5%	10%	85%
Interpreted from: Oregon Wood Innovation Center, 2009				

The energy density of woody biomass can be increased through torrefaction. Various manufacturers and developers of equipment report that the mass of woody biomass can be reduced while retaining a large percentage of the energy value of the raw material. Several questions remain about how and where torrefaction fits into the traditional and non-traditional forest products industries. This paper is a literature synthesis that presents information on (1) the torrefaction process, (2) current developments in commercial torrefaction equipment, (3) characteristics of and markets for torrefied wood, and (4) feedstock specifications for torrefaction.

Developments in commercial torrefaction equipment

A variety of manufacturers and researchers are developing torrefaction units for commercial use. A few are described in this section to provide an overview of the potential conversion manufacturers that are trying to enter the market.

Integro Earth Fuels, LLC (2010) reports that their torrefaction process reduces 20-30% of the mass while retaining 90% of its energy. Their torrefaction process operates in the temperature range of 240 - 270ºC. The company anticipates producing 4,000 tons of torrefied biomass each month in the pilot plant. Information gained from the pilot plant will be used to develop a full-sized torrefaction facility. Heating values of the final product range from 9,500 – 11,000 Btu/lb.

Southern pine species have an energy value of approximately 8,500 Btu/Lb (dry weight). Under this torrefaction process, the energy value from a dry ton of wood would be reduced from 8,500 Btu/lb to 7,650 Btu/lb (a 10% loss), however there are mass losses associated with the process. If the mass reduction from the process is 20%, the final product has an increased energy value of 9,563 Btu/lb, or a 12.5% increase in energy value.

Thermya, a French engineering company, has developed a continuous torrefaction process called TORSPYD. In April 2010, World Bioenergy News reported that Thermya was the only European company to offer an industrially proven, fully operational, continuous biomass torrefaction process. The system is reported to operate in the lower range of temperatures reported for torrefaction. TORSPYD processing operates in temperatures ≤240ºC (464ºF), a soft thermal treatment. Unit capacities can range from 100 kg/h to 5,000 kg/h. The final product is called BioCoal and is marketed as a coal substitute to be co-fired with coal or used in industrial boilers for producing electricity. The BioCoal can also be used in pellet manufacture, and eliminates the need for sawdust (Thermya, 2010).

Agri-Tech Producers, LLC, a company based in South Carolina, is reported to be nearing the completion of a commercial-grade torrefaction machine (James, 2010). Using technology developed at North Carolina State University, their process operates in a low-oxygen environment at temperatures ranging from 300 to 400ºC. The first commercial-grade machine is planned for completion during the summer of 2010. It will be called the Torre-Tech 5.0. The production rate of this machine will be five tons of torrefied wood per hour.

Researchers in The Netherlands are continuing research on a torrefaction process that began in the 1980s by a French aluminum company. Originally, the process was used to produce metal from metal oxides. Today, the current process is called TOP for torrefaction and pelletization. Early results in 2005 (Bergman and Kiel) indicate that a commercial scale plant could produce 60-100 green kton/year (approximately 66,000 – 110,000 green tons/yr) of high-energy torrefied pellets. Researchers indicate that TOP pellets could be delivered to power plants at a lower cost/Btu as compared to standard wood pellets. They attribute some of the cost savings to the pelletization process, but the majority of the savings is attributed to transportation logistics from transporting an energy dense product.

In 2009, Natural Fuels Industries, Inc. of Calgary, Alberta, Canada, announced plans to build biomass processing plants in Georgia (USA) and Brazil. The company plans to produce bio-coal briquettes using torrefaction technology. The briquettes will be shipped to European markets. In their initial announcement (Vega, 2009), they stated that there is a tremendous demand from European and American pulverized coal plants for bio-coal to meet cap and trade regulations and renewable portfolio standards for power generation.

There are many variables that can be attributed to the torrefaction process. The previous commercial developments discussion introduced the idea that a range of temperatures can be used in torrefaction. Another aspect of the process is the residence time, which can also vary. However, Fonseca et al (1999) determined that temperature has greater influence on the torrefied material than residence time. They recommend a temperature range of 250 to 300ºC with a residence time of less than 60 minutes.

In summary, a variety of conversion units using a torrifaction process are poised to enter the market. One barrier to commercialization is whether the markets are willing to bear the cost of the additional processing.

Characteristics of and markets for torrefied wood

There are other benefits of processing woody biomass through a torrefaction process. In addition to the changes in energy density, torrefaction changes other characteristics in the woody biomass. One of these changes is an increase in hydrophobicity. Because of the chemical changes in the structure of the torrefied wood, the end product does not absorb water. This property provides some advantages over green wood chips. Of particular interest is the ability to store the torrefied wood outside. Since the material will not absorb water, weather will not impact the quality of the product. For example, if wood is left in outside storage, it may increase in moisture. Southern Company found that wood chips delivered at 50% moisture content actually increased in moisture due to outside storage before it was conveyed into a power plant (Boylan et al, 2008). As these wet chips entered the boiler, the boiler was de-rated as a direct result of the moisture addition. Moisture content variations result in inefficiencies in energy conversion that cannot be accounted for in some existing power plant processes without the addition of a wood chip dryer or covered storage. This is just one example of how the hydrophobic characteristic of torrefied wood chips can be used to improve wood conversion processes and potentially create new markets for the forest products industry.

Another characteristic of torrefied wood is increased friability, or crushability. As wood chips are 'roasted', they not only lose moisture, but they become brittle. This characteristic could increase interest in the use of woody biomass in processes where raw materials must pass through a pulverizer or some type of crushing equipment, such as is commonly found in power plants to crush coal prior to entering the boiler. The moisture content and properties of green wood chips in these types of processes is not as conducive as either dried wood or torrefied wood because green wood does not possess this brittle, easily crushed characteristic. The power requirements to reduce the size of torrefied biomass are similar to coal, and in comparison, can be 70-90% less than the power requirements to reduce wood cuttings (Bergman and Kiel, 2005).

In the domestic household market, torrefied wood was tested in Europe as a replacement for charcoal used in grilling (barbecuing). Researchers (Girard and Shah, no date) surveyed users that compared using torrefied wood to traditional charcoal briquettes. Respondents indicated that the torrefied product was satisfactory in appearance and cleanliness; glowing embers formed more rapidly; the product appeared to be more appropriate to brisk cooking; and the absence of smoke during cooking was noted almost unanimously. However, objective measurements indicate that the ember phase is much shorter for torrefied wood than for charcoal.

Many of the handling issues associated with ‘bridging’ of wood chips in hoppers and the sheer volume of green wood chips required to produce an 8% mix by energy is often a barrier to using wood chips in power plants. Torrefied wood has been used to co-fire with coal or as a coal replacement in power plants. Compared to the coal it replaces, biomass reduces sulfur dioxide (SO_2), nitrogen oxides (NO_x), and net greenhouse gas emissions of CO_2 (Lipinski et al, 2002). Co-firing torrefied wood is more attractive than using raw biomass such as wood chips because the enhanced product is friable and can be blended, pulverized and co-fired with coal. The capital and operating costs for separate biomass fuel feed and firing systems are avoided.

A key advantage of the reduced mass and increased energy value of torrefied wood is the impact on transportation. A typical payload for a load of green chips is approximately 25 tons, or 50,000 lbs. Using an energy value of 4,500 Btu/lb (green weight), a load of green wood chips would contain 225 MMBtu. By comparison, when transporting a torrified wood product, the energy value of a 25 ton load could be 478 MMBtu, depending on the feedstock and torrefaction process used. By transporting a higher-valued product, the costs to transport energy (measured in BTUs) are decreased. Another consideration for the reduced mass is that storage space would be less for torrefied wood versus green chips.

In addition to use as a coal replacement or for backyard grilling, torrefied wood has other alternative markets. Other markets for torrefied wood include use as in the manufacture of metal, as feedstock in gasification processes, and for residential heating in boilers and wood stoves.

Feedstock specifications

Torrefied biomass can be produced from various sources of herbaceous and woody biomass while yielding similar product properties. Because the assorted biomass sources differ in physical properties that are sensitive to the torrefaction process, each will need specific operating conditions to yield similar product quality. Mass and energy yields will differ as the temperature and residence times are adjusted for different feedstocks (Bergman and Kiel, 2005).

Raw material is typically dried to 10% moisture content (or less) prior to torrefaction. This drying can be accomplished in a separate step, or even in separate kilns. After torrefaction, the moisture content can be reduced to <3%.

In addition to the biomass source, particle thickness can play an important role in torrefaction (Lipinksy et al, 2002). Due to increased heat transfer rates, reaction times are different for thinner chips versus wood chunks. In torrefaction systems that use a screw-type auger for continuous processing, heat transfer occurs as the wood particles come into contact with heated surfaces (Li and Gifford, 2001). This equipment requires a particle size of 10 mm or less. For systems that use a batch process, heat transfer occurs through conduction. Batch systems are not as sensitive to particle size.

Because torrefaction units are not currently commercially available, the conversion costs are not known. In lieu of that information, the spot coal price for the coal commodity region of Central Appalachia (12,500 Btu/lb) for the week ending on May 21, 1010 was $64.60/ton (EIA, 2010). If torrefied wood is used as a coal replacement, the cost of using torrefied wood should not exceed the cost of coal, measured in Btu/lb. If the torrefied wood has an energy value of 9,563 Btu/lb, then a comparable cost would be $49.42/ton. Torrefied wood costs should include stumpage; harvesting and transport of biomass; torrefaction processes; and any additional transportation costs. These costs should not exceed the cost of coal. If regulations require the use of renewable resources, perhaps buyers would be willing to pay more for torrefied wood.

Summary

The use of torrefied wood in commercial industry is still in development, even though torrefaction is not a new process. Several companies are developing commercial torrefaction equipment. The technologies under current development use a variety of combinations of temperature and residence time for processing woody biomass into torrefied wood.

There are a variety of proposed uses for torrefied wood. The hydrophobic and brittle properties of torrefied wood make it compatible with coal or as a coal replacement. In order for torrefied wood to compete in the coal market, the cost of producing torrefied wood, from the stump to the delivery point, must not exceed the price of coal deliveries. Other potential uses of torrefied wood include industrial boilers, residential heating, and for backyard grilling.

From the perspective of the logging and timber industry, literature indicates that raw material can vary in size and can include thin and thick chips, and even larger wood chunks. Depending on the equipment design, and considering characteristics such as pre-drying, processing temperature and reaction time; it appears that feedstocks for the torrefaction process could be produced by many of the types of in-woods processing equipment readily available on the market.

References

Bergman, P. and Kiel,J. 2005. Torrefaction for biomass upgrading. Energy Research Centre of the Netherlands. Publication No. ECN-RX—05-180. 6p.

Boylan, D.; Roberts, K.; Zemo, B.; and Johnson, T. 2008. Co-milling green wood chips at Alabama Power Company's Plant Gadsden unit 2. 59p. Accessed 5/24/2010 at www.cawaco.org.

EIA. 2010. Coal News and Market Report, report released 5/24/2010. Accessed on 5/25/2010 at www.eia.doe.gov.

Fonseca, F.F.; Luengo, C.A.; Beaton, P.; and Suarez, J. A. 1999. Efficiency test for bench unit torrefaction and characterization of torrefied biomass. BIOMASS: a growth opportunity in green energy and value-added products, Proceedings of the 4th Biomass Conference of the Americas, Oakland, California, USA. Ed. by R.P. Overend and E. Chonet. 3p.

Girard, P. and Shah, N. No date. Developments on torrefied wood an alternative to charcoal for reducing deforestation. Centre Technique Forestier Tropical. 7p. Accessed on 4/20/2010 at http://techtp.com/tw%20papers/fao_paper.htm.

Integro Earth Fuels, LLC. 2010. Integro Earth Fuels announces pilot torrefaction plant. Accessed 4/20/2010 at www.integrofuels.com

James, J. 2010. Using torrefied wood as a coal replacement, for superior pellets and cellulosic ethanol production. Agri-Tech Producers, LLC; Columbia, SC. (presentation)

Li J. and Gifford,J. 2001. Evaluation of woody biomass torrefaction. Accessed on 4/22/10 at http://techtp.com/recent%20/ TW%20New %20Zealand.htm. 4p.

Lipinsky, E; Arcate, J.; and Reed T. 2002. Enhanced wood fuels via torrefaction. Fuel Chemistry Preprints 47(1). 3p.

Oregon Wood Innovation Center. 2009. Energy from wood. Presented at the Forest Biomass Fast Pyrolysis Demonstration, Douglas County, August, 2009. (presentation)

Thermya. 2010. A continuous torrefaction process from France. Accessed 4/27/2010 at www.thermya.com.

Vega Promotional Systems, Inc. 2009. Promotional newsletter dated 12/22/2009 accessed on 4/27/2010 at www.vegabiofuels.com.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Optimization of pyrolysis procedure for improved moisture resistance and reduced material costs in wood product manufacture.

Robinson, T.J., Via, B.K., Tu, M., Adhikari,S., Fasina, O., and Carter, E.

Poster

With the increase in global demand for petroleum-based products, plant-based substitutes are becoming more attractive. Previously, lignin based products from wood has shown to deter the growth of wood degrading microorganisms. We have proposed to extend this to pyrolysis oil where the phenolic compounds from lignin is high in concentration and should provide resistance to brown rot degradation. In this work, the use of pyrolysis oil as a moisture resistant treatment for wood was explored to determine the applicability and optimal conditions for wood impregnation. The pyrolysis oil was separated into its non-aqueous and aqueous phases. The non-aqueous phase, rich in phenolics, was then diluted to varying degrees with methanol (and other solvents) and impregnated into solid wood elements using either vacuum soak, pressure soak, or direct application prior to hot-pressing. Combinations of these techniques using varying soak time and pressures were also explored to determine the methodology for attaining the greatest retention of the non-aqueous phenolic fraction. Optimization of each process for moisture resistance will be performed and the resulting input material costs will be determined by considering the ratio of performance to cost.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Developing a New Generation of Woody Biomass Harvesting Equipment

Bob Rummer[1], Steve Taylor[2], Frank Corley[3]

Abstract: The southern US is one of the most productive forest regions in the world and it will play a significant role in meeting the projected demand for renewable energy feedstocks. However, in order to provide large volumes of woody feedstock at acceptable cost there will have to be development of new intensively managed stands and the simultaneous development of new harvesting technology. A team of university, government, and industry partners is developing a new system that envisions operations in pine plantations, managed for relatively short rotations (12-14 yrs) as an energy-only crop. The focus of the project is development and testing of new felling, extraction, processing and transportation technology that can achieve high fuel and cost efficiency. In addition the project will be defining the productivity and cost of conventional harvesting operations in these types of stands for comparison purposes. This paper describes the proposed system and the developments that can improve efficiency.

Introduction

Forests are important to the US South. A little more than half of the southern US, approximately 211M acres, is forested (Wear 2002). These forests support a significant forest industry, recreation, wildlife, and provide many other social and ecological values. Over half of total US roundwood production comes from the region making it the most productive forest region in the world with more forest products output than any other single country (Table 1). Southern forests and forest industry face many challenges including global competition, cyclic demand for traditional products, urbanization, fragmentation, climate change, and the recent overall economic downturn. Southern forest landowners are looking for new ways to recover value from resource ownership. Southern forest industry is trying to remain competitive while converting forest resources into globally-traded products.

Table 1. Total industrial roundwood production, 2008 (UNFAO 2010)

Country	Production (m^3)
United States	336,611,000
Canada	152,638,000
Russian Federation	136,700,000
Brazil	115,390,000
China	95,819,100

The developing bioenergy industry is both a challenge and an opportunity with the potential to have a major impact on southern forests. Sourcing woody biomass for energy production could add value for landowners but will certainly introduce competition for the resource and affect raw material prices. In an announcement about the world's largest biomass power plant (350MW) in Wales, it was stated that 3M tons of wood chips per year will be sourced from "… sustainable forests outside the UK, including the US South." Announced wood biomass projects in the US would add at least 80M tons per year of demand if all were completed (RISI, 2010). About half of the potential demand would be for power generation projects. Increased demand for forest production leads to efforts to increase supply. While

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some volume of logging residues will be available it is clear that a viable bioenergy industry will not be able to rely on a feedstock that is a “waste” or co-product from another industry. Thus, new demand will lead to expansion of productive forests. This could occur through intensification of management on existing forest acres (more growth per acre) or through afforestation and new plantation forests. In the southern US, much of the interest will rely on native southern pine species, particularly loblolly pine. Fox, Jokela, and Allen (2004) provide a review of the development and current practices in southern pine plantation silviculture.

In 2009, a consortium formed and developed the concept of reducing woody biomass feedstock delivered cost by optimizing a system around a very consistent resource—an intensively managed pine plantation. Partners include Auburn University, Corley Land Services, the US Forest Service and Tigercat. Current ground-based harvesting and transportation systems are designed to handle a range of piece sizes and stand conditions resulting in system-level inefficiency and higher costs for any given piece size. How efficient could a logistics supply system become if the stand and feedstock parameters were narrowly defined to meet the needs of bioenergy consumers? This paper will describe the proposal to develop and demonstrate a new woody biomass feedstock delivery system based on intensive pine plantation management. The system will be deployed and tested beginning in 2010.

System Description

The starting point for energywood harvesting system design is consideration of the type of feedstock resource. In the southern US, an intensively managed pine plantation system offers a number of advantages including:

1) Well-known regeneration and silvicultural practices
2) Widely available (and thus relatively inexpensive) planting stock
3) Native species
4) Alternative product options to hedge future harvest risk (ie, thin and continue to sawtimber)
5) Relatively frequent harvests with income streams

Borders and Bailey (2001) reviewed studies of intensive loblolly pine silviculture and concluded that “current growth rates … fall short of their potentials.” Average sites in Georgia had growth rates of 90 to 135 ft^3/ac/yr while intensive management resulted in Mean Annual Increments of nearly 500 ft^3/ac/yr with fertilization and competition control. They conclude that intensive management can significantly increase yield and reduce rotation age. Shiver and Harrison (2004) report on studies of loblolly in Georgia. Plantations were established at a range of densities from 300 to 1800 trees per acre. Interim results at age six showed that higher establishment density and more intensive management practices resulted in higher total stand volume. Higher density (trees per acre) captures more site potential early in stand development. If energywood is the ultimate product, high density stands would produce more volume in a short rotation and could be cut as the stand neared maximum stand density index. Based on studies like these the proposed pine energywood system would be established at 1000 trees per acre and intended for clearcut harvest at age 12. Fertilization and vegetation control would be used as needed. The resulting stand would have relatively uniform stems approaching 10 inches dbh. Assuming intensive management and additional improvements in genetics result in yields of 6 to 7 dry tons per acre per year, an annual supply of 100M dry tons per year could be produced from a landbase of about 17M acres (approximately half of the area of current southern US pine plantations).

A bioenergy pine plantation presents several unique features that affect harvesting operations. Trees will be slightly smaller (diameter and height) and there will be more trees per acre than in conventional timber harvests. Felling productivity will be affected with more tree-to-tree movement and more frequent move-to-dump motions. Skidding productivity may also be impacted as bunches could have less volume and there will likely be more bunches per acre to collect. The final processing step will also be different, focused on whole tree reduction to bioenergy feedstock specifications (small uniform chip size, perhaps bark or dirt constraints). All of these features of bioenergy pine culture support the need to develop a new mechanized system, optimized for this application.

Current high production pine harvesting systems are generally configured with a rubber-tired feller-buncher and grapple skidders. Felled trees are merchandized to recover either pulpwood or sawlogs with some form of mechanical delimbing and bucking. Residues are generally left behind. Productivity of a typical southern pine mechanized harvesting system at final harvest can exceed 300 tons per day. Logging utilization studies suggest that approximately 15 to 25 percent of total volume felled is left behind as logging residues (Stokes and Watson 1991). While the basic functional requirements are the same in bioenergy applications, if the feedstock properties are more consistent, a ground-based system could be modified to improve efficiency. Specific system developments that will be implemented in the new system will include:

1) Felling will be optimized for clearcut harvest of small trees using a swing-to-tree machine that can access multiple rows with less trafficking. Move-to-tree time will be dependent on swing performance rather than driving performance which may be more efficient in small evenly-spaced trees. The felling head will be modified to consider the basal area and mass of 12-yr-old pines. This is important to minimize dump time per ton produced. Productivity can be improved by sizing the felling head to accumulate a larger load before dumping. Additional refinements will include consideration of operator controls/ergonomics and improvements to power transmission components for efficient boom operation. Spinelli and Hartsough (2006) measured swing feller-buncher performance in poplar energywood plantations planted at a density of about 800 trees per acre. Trees averaged 6.5 inches dbh and productivity averaged about 430 trees per productive hour.

2) Skidding with grapple skidders will remain essentially the same. Critical performance variables include total payload, bunch size, and skid distance. While plantation layout will likely remain the same (and thus average skid distance), the new system will allow larger bunches to be developed by the feller-buncher that should be close to the maximum payload size for the skidder. Optimum bunch size is a function of the grapple opening (maximum area) and piece parameters (basal area and volume). The new grapple skidder will be specifically designed to match grapple opening with horsepower and estimated energywood dimensions to minimize cost per ton. Other modifications include ergonomics and operator controls to facilitate rapid cycle times. Ideally the production of the skidder will match the capacity of the feller-buncher for a one-to-one system configuration.

3) Processing technology will be evaluated in this study with a range of conventional equipment. This step in feedstock production is highly dependent on end user specifications (Mitchell 2006). Different equipment can address different requirements. For example, bark content can be modified through debarking and by limbing or topping prior to comminution. Particle size can be controlled through screens, type of comminution (i.e., chipping vs. grinding), input feedstock parameters, and control of processing variables like feed rate. Potential bioenergy particle specifications are not clearly defined at this point given the wide range of potential conversion processes. However it is clear that an optimal production system needs to be able to control size, size distribution, moisture content, and have an option for bark removal. The project will run tests with drum chippers, disk chippers, and horizontal grinders with and without debarking. Field-dried material will be compared to green by operating both hot and cold system configurations. Additionally we will be testing the effects of processing scale by evaluating high-capacity comminution systems.

4) Transportation is conventionally assumed to account for up to half of delivered feedstock cost. Transport cost is a function of cycle time (distance, loading and unloading) and payload. Cycle time effects will be explored by instrumenting trucks to quantify routing and travel speeds and terminal times. High production operation (>20 lds per day) introduces opportunities for scheduling and logistics management technology to minimize cycle time. Payload is generally limited by highway regulations. Thus, the only opportunity to increase payload significantly is to dry the feedstock prior to transport. Studies of field drying southern pine suggest that moisture content may be reduced from 50 percent to 30 percent over a 2 to 3 month period (Klepac, Rummer, Seixas 2008). Assume conventional forest products transport in Alabama costs $0.12/ton-mile. At an average one-way haul of 60 miles, a 28 green ton load would cost $201.60 or $14.40 per dry ton (at 50 percent moisture content). If the same truck could max out payload with field-dried feedstock at 30 percent moisture content, the transport cost per dry ton would be reduced to $10.29 per dry ton. This development means that larger cubic capacity trailers will have to be deployed. A new trailer design will be developed and tested during the project.

5) Finally, system management strategies will be tested with the new equipment to find additional efficiencies. Clearcut harvesting with a completely mechanized system, for example, is highly amenable to extended shift operations. Cold logging can eliminate interference delays between functions and increase productivity. Remote machine monitoring and communications systems can quickly identify system interruptions and minimize response time. Each of these technologies will be tested to examine where additional value/reduced cost can be achieved. Precision forestry tools, for example, can provide spatial information that may have additional value for landowners. Information about stand volume could be used to identify where fertilization would be most effective. Map displays may help equipment operators plan more efficient working patterns.

A key element of this project is to develop a life cycle assessment (LCA) of the biomass feedstock production system. LCA is a methodology to enumerate all the inputs and outputs for a given system and calculate a "score" in some meaningful metric like tons of CO_2 equivalents. To compare the new feedstock system to woody biomass sourced from thinnings or logging residues we will estimate inputs for all activities from site preparation and stand establishment through harvesting and transport. Detailed data will be collected on fuel consumption for the various operations using real-time sensors integrated with production data to give gallons/ton produced.

Additional assessments will be conducted to address questions of sustainability. Obviously intensive plantation management raises questions about long-term site productivity and nutrient depletion. Fertilization and herbicide introduce additional issues that will be monitored and addressed. Water quality effects of intensive site preparation will be examined. Finally, shorter rotations and denser stands may alter wildlife habitat. As a Federally-funded project, a National Environmental Policy Act (NEPA) assessment will be developed to identify key issues of concern. Field measurements will be taken to quantify critical variables like removals, trafficking, soil exposure and soil water quality.

Project Timeline

The total project is a 3-year program of development, test, and commercialization. Phase I will include a benchmarking study to define the performance and cost of current woody biomass harvesting systems. This will provide information that will clearly identify where efficiency and cost reduction are achieved. During this phase, development of the new feller-buncher and skidder will be completed and the precision forestry applications will be designed and tested. A Project Advisory Committee, consisting of representatives from biorefineries, forest industry, utilities, and other feedstock users will be convened to provide input on the range of feedstock properties that should be considered. Phase I should be completed in about 9 months.

The second phase will be to deploy and test the new system across a range of operating conditions. The intent is to conduct production-scale operations in the various alternatives (hot vs. cold logging, field drying, extended shifts, debarking, etc.). An important element in Phase II will be focus group meetings to gauge acceptance of the new system by landowners, logging contractors, and resource managers. These groups will provide a subjective critique of factors that may not be apparent through the traditional industrial engineering studies of time and motion.

The intent is to have the new technology prepared for commercialization at the end of the project. Through analysis, reports and field demonstration there should be a clear understanding of what a forest landowner could expect if they elected to intensively manage pine. Logging contractors should be able to clearly understand the costs and operational requirements of the new system. Feedstock customers will have better knowledge of delivery system operation and how their feedstock specifications can affect delivered cost.

Summary

Delivered feedstock costs need to be reduced to support a viable bioenergy industry. DOE has proposed a target of $46 per dry ton (delivered) by 2012 (DOE 2009). By developing logistics operations that are optimized to the unique properties of intensively managed plantation stock we feel that we can achieve the DOE target goal. In addition, the project will deliver significant information about the performance and cost structure in woody feedstock logistics. The initial phase of the project began May 2010 with benchmarking current woody biomass systems. The new equipment will be deployed by 2011 and will be tested over a 2-year period.

Acknowledgement

This project is jointly supported by the Department of Energy and the project partners.

References

Borders, B.E. and R.L. Bailey. 2001. Loblolly pine—pushing the limits of growth. Southern Journal of Applied Forestry. 25(2):69-74.

DOE. 2009. Biomass multi-year program plan. US Department of Energy, Office of Biomass Programs. 201 p.

Fox, T.; Jokela, E; Allen, H.L. 2004. The evolution of pine plantation silviculture in the US South. In: Southern Forest Science. Past, present, and future. Gen Tech Report SRS-75. Asheville, NC: USDA Forest Service, Southern Research Station. P. 63-82.

Klepac, J., Rummer, B. and F. Seixas. 2008. Seasonal effects of moisture loss on loblolly pine. In: Proceedings of the 31st Council on Forest Engineering Annual Meeting. Corvallis, OR: COFE. P. 53-61.

Mitchell, D. 2006. Perspectives on woody biomass fuel value and specifications in Alabama. Paper 06-8050. St. Joseph, MI: American Society of Agricultural and Biological Engineers. 7 p.

RISI. 2010. Wood biomass market report. Vol 3, Number 4.

Shivers, B.D. and W.M. Harrison. 2004. PMRC SAGS culture/density study: age 6 analysis. Technical Report 2004-2. Athens, GA: Plantation Management Research Cooperative, Warnell School of Forestry. 17p.

Spinelli, R. and B. Hartsough. 2006. Harvesting SRF poplar for pulpwood: Experience in the Pacific Northwest. Biomass and Bioenergy 30:439-445.

Stokes, B. and B. Watson. 1991. Wood recovery with in-woods flailing and chipping. TAPPI Journal 74(9):109-113

United Nations Food and Agriculture Organization. 2010. FAOSTAT forestry data. http://faostat.fao.org [Date accessed: May 13, 2010]

Wear, D. 2002. Chapter 6 Land use. In: Southern Forest Resource Assessment. Gen Tech Report SRS-53. Asheville, NC: USDA Forest Service, Southern Research Station. 635 p.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

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Paper Title:
Effectiveness and Costs of Five Skid Trail Closure Techniques in the Virginia Piedmont

ABSTRACT

The Reynolds Homestead Forest Resources Research Center, located in the western Piedmont of Virginia, is overseen by the Virginia Tech College of Natural Resources for the purpose of forestry research, education, and management. A timber harvest plan was developed and implemented on a twenty-nine acre parcel at the center in order to study the effects various harvest closure techniques have on erosion of overland skid trails. One focal point of the project is to determine accurate costs to install Best Management Practices (BMPs) after finalizing a timber harvest. Four main skid trails with similar slope, length, aspect, and soils were selected for the study. Water bars were constructed on the skid trails approximately every fifty feet. The five skid trail closure techniques - the application of pine slash, hardwood slash, grass seed only, grass seed covered by straw mulch, and water bars only - were randomly distributed on the fifty feet sections of skid trail. All associated costs for these applications will be analyzed. The compacted soil on the log deck was prepared by sub-soiling and disking before applying seed. All areas where grass seed was applied also received an application equivalent to two hundred pounds per acre of fertilizer and two thousand pounds per acre of lime. Other BMP costs examined for the timber harvest include the re-grading and re-vegetation of a heavily rutted skid trail. Typical methods and equipment were used for these applications. The total costs accumulate until the BMP specifications are met according to *Virginia's Forestry Best Management Practices for Water Quality, Fourth Edition*.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Modeling forest biomass in atmospheric carbon reduction in West Virginia

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Abstract

An analytical modeling framework was developed for estimating current as well as potential carbon (C) emission reduction through utilization of available forest biomass. The net C balance under current biomass use and its contribution to atmospheric C reduction was assessed under different management options ranging from biomass co-firing during power generation, extending the life of wood products, burying unused wood residues in landfills for long periods of time, and finally using integrating biomass co-firing and carbon capture and storage (CCS) technology. The study used forest biomass data in West Virginia and utilized C stock and C flow models over time to quantify the emission as well as sequestration of C. Results indicated that the current biomass use for energy production saves 0.27 million tC from entering into the atmosphere annually in WV and there is potential to achieve up to 1.57 million tC of annual emission savings through sustainable biomass production and utilization. Implementation of other options such as CCS and co-firing would result in about 4% emission reduction from current C emission levels in the state. The modeling framework can be applied in any regions.

Introduction

Renewable forest biomass is an important carbon storage pool, especially in forested regions where abundant biomass resources are available and obtained from sustainable forest management practices. These renewable resources store atmospheric carbon (C) through the process of photosynthesis, and if used for energy production, do not increase emissions to the existing atmospheric C pool. Therefore, biomass utilization is a viable alternative to fossil fuels, not only because it can partially displace this expensive fuel source, but also because it provides carbon emission reduction potential. West Virginia has over 80 percent of its land covered in forest cover and produces vast amounts of biomass resources which are utilized in different product types ranging from long-lasting saw logs to short-term products such as pulp and paper. Recent studies, however, have shown that biomass resources are underutilized in the state (Wang et al. 2007, Sharma 2010). Studies dealing with potential energy production have shown that the unused biomass in the state can replace a large amount of fossil-based fuel sources (Sharma and Wang 2010). Convential biomass resource analyses have focused on potential energy production through biofuels such as ethanol production, heat generation and co-firing to complement the rising energy costs. This paper addresses another benefit of utilizing biomass; CO_2 emission reduction, while also discussing the role of biomass utilization and atmospheric C sequestration in meeting low C emission energy demands.

Methods

Carbon stock and flow across temporal horizons were considered in different biomass uses. The biomass available at any point in time is a function of available resources, net growth and net removal (Sharma and Wang 2010). Information on C in harvested wood and applicable end uses were obtained from Timber Products Output (TPO) data. Energy production and C emissions reduction through replacement of coal fuel with biomass for energy production were obtained from available conversion factors applicable for WV (USDA-FPL 2004, Wang et al. 2007, WVPF 2009).

Carbon content in woody biomass was estimated as half of the total biomass (Eq. 1). The biomass content removed from the forest was obtained by using volume-density relationship (USDA-FPL 1953, Grantham and Ellis 1974, Smith 1991) of different species (Eq. 2). During the period of 2000 to 2006, the net growth to removal ratio (Eq. 3) of forests in WV was about 1.5 in terms of volume of growing stock (Sharma et al. 2010, USDA-FS 2009). This ratio implies that 40 percent of current growth is harvested while the remaining 60 percent is left standing. This ratio was even higher in previous years; i.e., 2.1 in 1994 and 2.0 in 1979 (Widmann et al. 1998). Removal of C occurs when forests are harvested. This stock is estimated using Eq. (5). The harvested products emit C into atmosphere through the process of decomposition and decay and often go through several production stages during their lifespan. Depending on the usage, these products would have a variable product life and varying amounts of C stored at different times. The amount of C remaining in a product was estimated by using an exponential decay function with half-life of C for a particular product type (Table 2) using Eq. (6) (Karjalainen et al. 2002). When harvesting occurs each year, the resulting annual value of C in harvested products can be estimated by using Eq. (7). The carbon content in different product categories is shown in Figure 1.

$$B_c = 0.5\ B \qquad (1)$$

$$B_s = V_{B_i} D_{B_i} \quad \text{for i = 1, 2, ..., species group s} \qquad (2)$$

$$ACR = \frac{ACA}{GRR} \qquad (3)$$

$$Q_y = \sum_{n=1}^{N} Q_n * \left[1 - \frac{\ln(2)}{h_n}\right]^{(y-1)} \Big\} \quad (4)$$

$$Q_y = \sum_{n=1}^{N} Q_n * \left[1 - \frac{\ln(2)}{h_n}\right]^{(y-1)} + c \sum_{i=2}^{y} \Delta Q_n \left[1 - \frac{\ln(2)}{h_n}\right]^{(i-2)} \Big\} \quad (5)$$

where B_c is carbon in removed forest biomass, B_s is biomass content in tons for species group *s*, V_{bi} is volume of biomass removed in cubic feet for species group *i*, D_{bi} is density of biomass removed from species group *i*, GRR is growth-to-removal ratio (> 0), ACA is annual C accrual (in million tons) in forest ecosystems, ACR is annual carbon removed (million tons) from forest ecosystems, Q_{t+1} is quantity of carbon at time y, Q_n is quantity of carbon at the beginning of n^{th} product, *Y* is the number of years for which simulation is needed, *y* is any future time period between 1 and *Y*, N is the number of different products from forest harvest, n = any product between 1 and ∞, h_n is expected half life of product *n*, t is time period (year), ΔQ_n is the quantity of addition to previous stock in the n^{th} category, i = 1...*y* where *y* >= 2, c = 0 if *y* < 2 and 1 otherwise. Parameters used in the model were obtained from several data sources and are listed in Table 1.

Table 1. Model parameters and their sources.

Parameter	Definition	Source
ACA	Annual carbon accrual in forest	Sharma 2010
GRR	Growth to removal ratio	USDA-FS 2009
V_{Bi}	Volume of biomass (m3) in species i	TPO data 2009
D_{Bi}	Density of biomass (t/m3) in species i	USDA-FPL 1953, Grantham and Ellis 1974

Table 2. Estimated half life of carbon in different wood products.

SN	Category	Half life years)	Applicable products
1	Long term product	30	Sawlogs; composite products
2	Medium term product	15	Post, poles and pilings; veneer logs; fiber
3	Short term product	1	Fuelwood; pulpwood
4	Landfills	145	Discarded residues
5	Dump and let decay	5	Unused products

Source: Karjalainen et al. 2002, Schelhaas et al. 2004, Zeng 2008

Different scenarios of forest biomass production and utilization were simulated representing current situations, increased production, enhanced utilization of unused products, and efficient management of unused products to extend the life of biomass products and possible biomass co-firing and CCS options to assess each strategies' impact on C emission and possible C sequestration enhancement through biomass utilization.

Results

Carbon sequestration in biomass

Harvested wood products (HWP) constitute C stock which is sequestered in the forest from the atmosphere through the process of photosynthesis and sequestered in wood products, thus contributing to lower atmospheric C (Dixon et al. 1994). The scale of net reduction in C depends on the final end use of the wood products. Forest harvests in WV have been consistent at the rate of about 7.71 million m^3 per year which includes logging residue left on the forest floor, and mill residues after primary processing. This total does not include removal from cultural operations conducted during the forest rotation cycle. The harvested wood is then transformed into different product types and a proportion of the harvested wood products ends up as "unused" products such as mill residues and logging residues. These "unused" products are estimated to be approximately 34 percent of the total harvested wood by volume (Fig. 1). The harvested volume from the existing forest growing stock amounts to 2.26 million tons of C per year. These removed products are not considered "a loss" if they can be put to different uses other than disposal by burning. The net carbon storage over a 100-year period assumes an equal amount of harvest every year (i.e., an annual removal of 2.26 million tons of carbon would indicate that the forest would make a total of 226 million t C stocked in wood products). Due to decay and several short term uses and subsequent emissions, this stock would shrink to a total of 43.33 million tC under the base case scenario (Fig. 2). If the forest can sustainably grow this amount and use patterns remain the same for a defined period of time, almost 4/5th of C in HWP is emitted back to the atmosphere, and remaining 1/5th remains stored, assuming that the cycle continues with the same level of utilization.

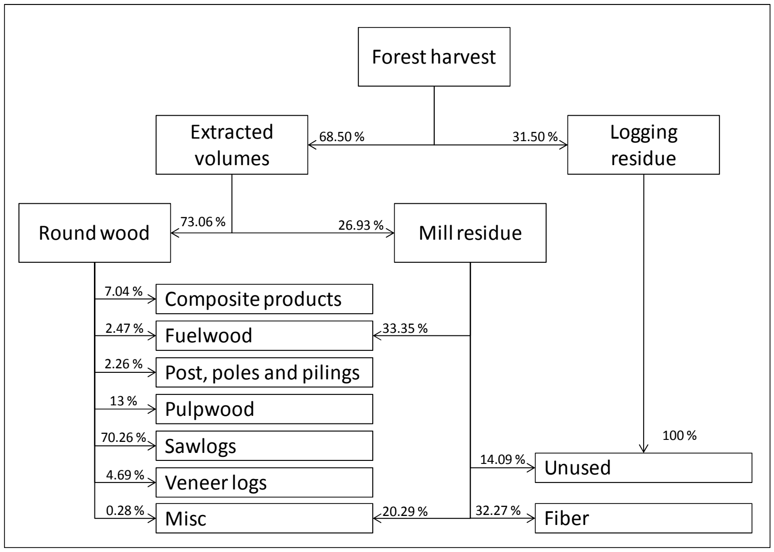

Figure 1. Harvested wood products usage (by volume) in West Virginia (percentage)..

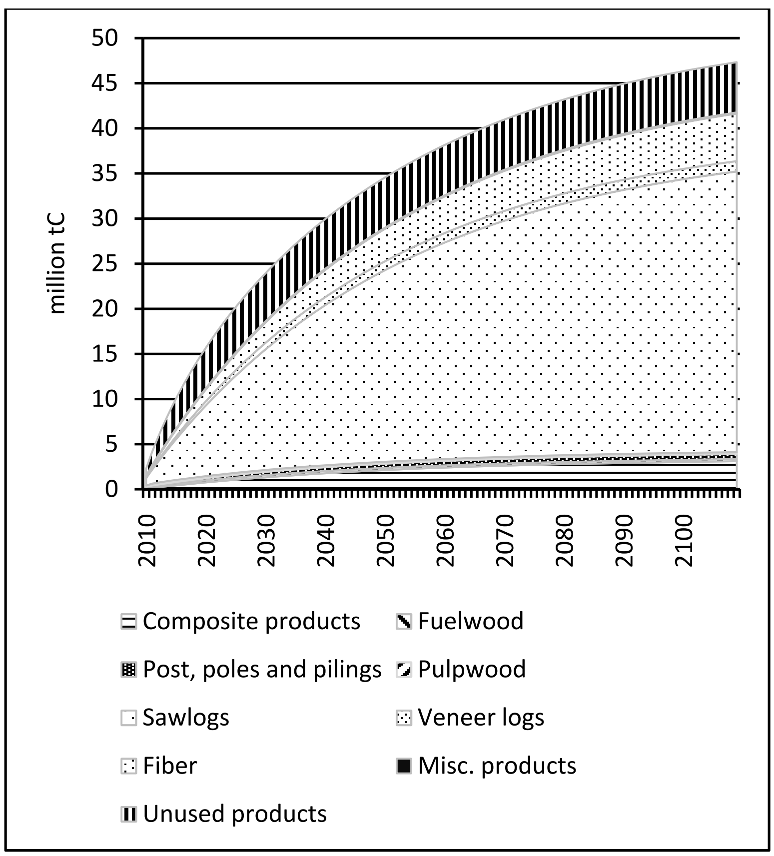

Figure 2. Current carbon storage in woody biomass in WV.

Emission and energy savings from biomass utilization

Currently, approximately 7.4 percent of harvested forest products are being used as fuel wood to produce energy (Fig. 1), emitting approximately 0.17 million tC into the atmosphere and suppling about 5862 kJ of energy. If this amount of energy had to be produced from coal it would emit approximately 0.11 million tC into the atmosphere. Since these mill residues would be left unused, they would eventually decay and emit C into the atmosphere, thus making the net emission of 0.28 million tC. Currently, WV produces about 1.5 million t of “unused” logging residues. These residues continuously emit 0.784 million tC into the atmosphere through decomposition and decay. This unused biomass has the potential to produce approximately of 27,061 billion kJ of energy, and can offset 0.58 million tC emitted from coal burning. Thus, the net emission benefits of 1.3 million tC can be achieved by utilizing all the unused biomass for energy production. When the emission savings from current fuel wood and potential usage of unused residues are combined, biomass energy utilization would have a net benefit of 1.54 million tC, which is approximately 1.8 percent of the state’s total emission. A comparison of current and potential emission savings are shown in Fig. 3. When such a situation is applied, the carbon stored in wood would shrink to 42.88 million tC (Fig. 4), which is about 9% less than that which would have been achieved under the current usage pattern.

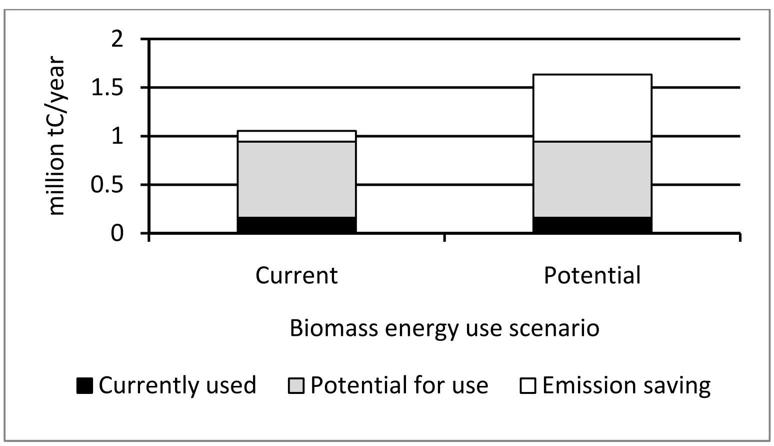

Figure 3. Annual estimate of current and potential emission savings through biomass energy use in WV.

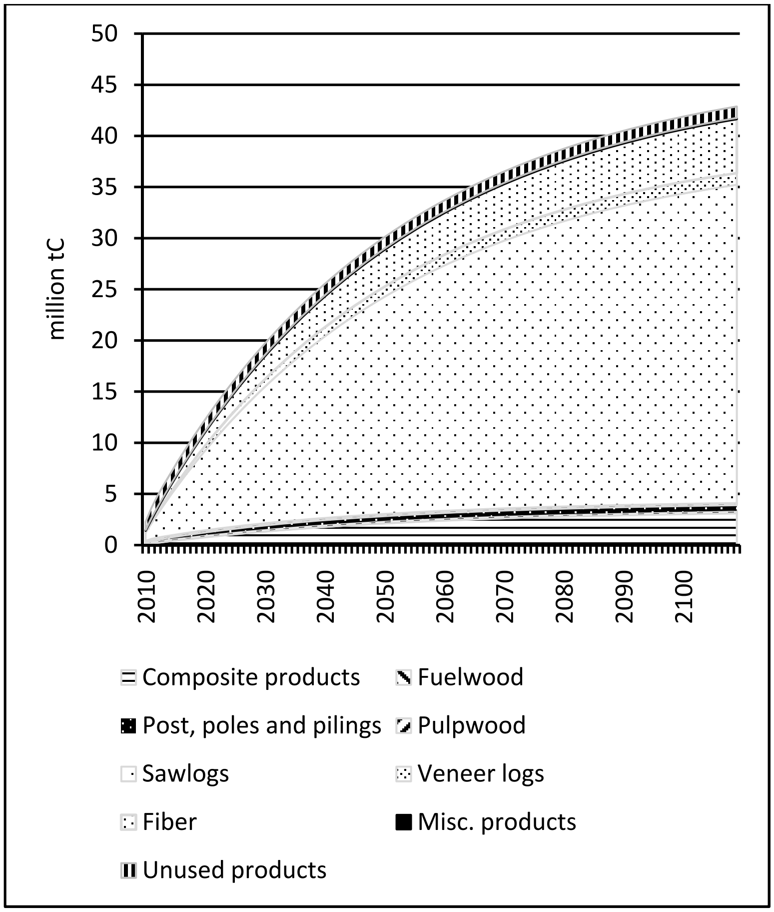

Figure 4. Carbon stored in wood products when all unused biomass is used as a substitute for fossil fuel in energy production..

Biomass utilization and carbon sequestration enhancement potential

Historically, growth to removal ratios have varied in range from 3.78 to 1.3 (The Charleston Gazette Online 2009, Widmann et al. 1998). Although a growth to removal ratio of 1 is theoretically possible, one must consider the potential risks. For example, when forests are managed under this ratio, there is no margin for detrimental effects of insects, diseases, and climate changes. Thus, a ratio of 1.25 was considered optimally sustainable in this analysis based on a previous study by Sharma and Wang (2010). Such a ratio would bring additional growing space in forests to allow for additional C sequestration by putting more C in harvested wood products, and supply more biomass to replace emission from fossil fuel. Besides sequestration, preventing the stock in harvested pools from decay can help achieve higher C stock levels. For example, the unused residues that account for approximately 1/3rd of the total harvested carbon from the forest are left in the forest to decay. If such decay is prevented, either through utilization such as in wood-plastic composites (WPC) or using land-fill options to extend the life of these residues, the state's carbon stock in harvested wood products would increase significantly (Sharma 2010), (about 50%) as shown in Fig. 5.

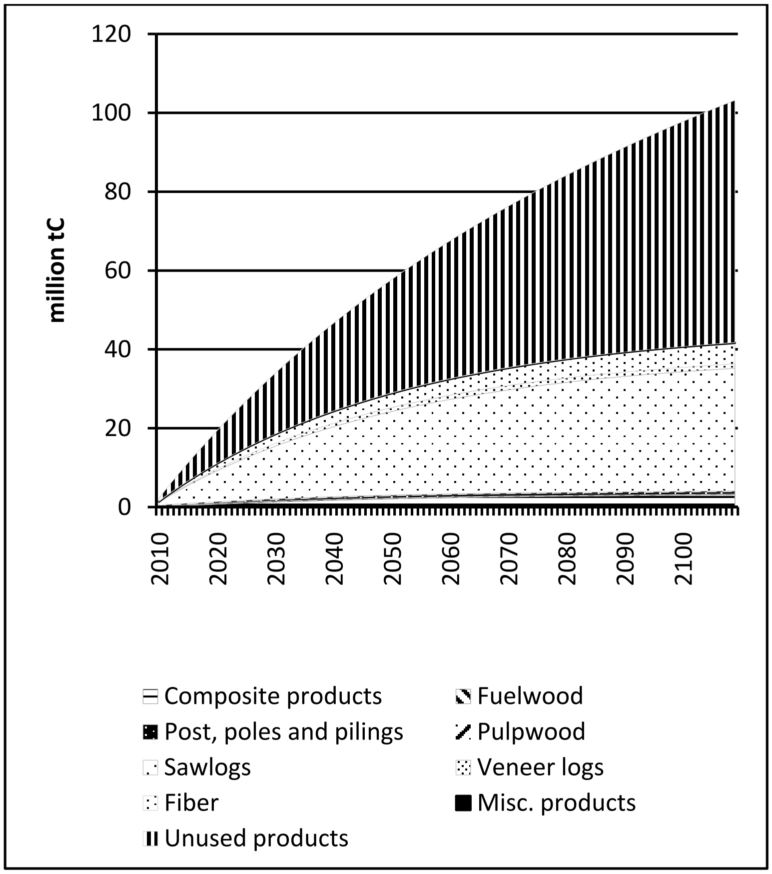

Figure 5. Carbon stored in wood products when all unused biomass is managed in a land fill to prevent quick decay.

Biomass co-firing and CCS options

The CCS alone can provide a significant amount of C sequestration from power generation. The potential benefits of this technology can be up-scaled by utilizing the biomass residues that are left on the forest floor during power generation process. This will enable the C negativity which could become an even better form of GHG mitigation measure.

The annual removal or production of forest biomass residues, including logging residues and mill residues, is equivalent to 2.5 million tC, of which 34 percent or 0.85 million tC remains unused or left to decay. This biomass can be used as a potential energy sources for co-firing in power plants. The annual C emission from coal during power generation is 23.75 million tC (USEPA 2009) to produce energy equivalent to 1064,000,000 million BTUs in West Virginia (WVPF 2009). The current estimate of unused biomass is 1.7 million tons which will emit a total of 0.85 million tC if burned to produce energy equivalent to 29,240,000 million BTUs. When coal is substituted for this biomass only 23.10 million tC is emitted from coal to produce the same energy in power generation, resulting in a net 2.75% reduction of C emission in this process.

Under a sustainable harvest, there is a potential to increase the level of harvest in WV which would produce additional 0.64 million tC of biomass available for energy production. This would help substitute an additional 1.03 percent of C emission from coal resulting in a net C emission saving of 3.78 percent from the current level. When biomass and coal fuel are combined with CCS, the emission from a portion of biomass-based carbon could be pulled back from atmosphere under sustainable forest management and net carbon emissions would start becoming negative each year by 3.78 % to achieve the maximum positive benefits from CCS undertakings. The current coal-biomass feed system for pressurized gasifiers allows mixing up to 30% of biomass in power generation (NETL 2007); therefore, biomass co-firing with CCS is within the range of feasible system. This framework also suggests that WV has the potential of increasing biomass feedstock for energy production and subsequent utilization for carbon emission reduction through the utilization of marginal lands, sustainable forest management and carbon efficient forest harvesting as described in Sharma (2010).

Conclusions

Unutilized biomass does very little to reduce atmospheric C levels, but if utilized for energy production, it would reduce the C emission from fossil fuel. Simply extending the life of biomass can help delay the increase in atmospheric C. When biomass is mixed with coal in power generation and combined with CCS, there would be a net negative emission in the system which would not only control the emission but actually reduce the emission from current levels. The modeling approach utilized in this study could be enhanced in the future by including costs for each strategy discussed for a broad application.

References:

Dixon, R.K., Brown, S., Houghton, R.A., Solomon, A.M., Trexler, M.C., Wisniewski, J. 1994. Carbon pools and flux of global forest ecosystems. Science 263:185–190.

Grantham, J.B., Ellis, T.H. 1974. Potentials of wood for producing energy. Journal of Forestry 72:552-556.

Karjalainen, T., Pussinen, A., Liski, J., Nabuurs, G.J., Erhard, M., Eggers, T., Sonntag, M., Mohren, F. 2002. An approach towards an estimate of the impact of forest management and climate change on the European forest sector budget: Germany as a case study. Forest Ecology and Management 162:87-103

NETL [National Energy Technology Laboratory]. 2007. Increasing security and reducing carbon emissions of the U.S. Transportation sector: A transformational role for Coal with biomass. DOEl/NETL-2007/1298.

Schelhaas, M.J., van Esch, P.W., Groen, T.A., de Jong, M.K., Kannienen, M., Liski, J., Masera, O., Moheren, G.M.J., Nabuurs, G.J., Palosuo, T., Pedroni, L., Vallejo, A., Vilen, T. 2004. CO2FIX V 3.1 – A modeling framework for quantifying carbon sequestration in forest ecosystems. Wageningen, NL.

Sharma, B.D. 2010. Modeling of forest harvest scheduling and terrestrial carbon sequestration. Ph.D. Dissertation. West Virginia University, Morgantown, WV. 160 p.

Sharma, B.D., Wang, J. 2010. Status and potential of terrestrial carbon sequestration in West Virginia. Manuscript accepted for publications into the proceedings of the 17th Central Hardwood Forest Conference April 2-5, 2010. Lexington, KY. Gen. Tech. Rep. NRS, U.S. Department of Agriculture, Forest Service, Northern Research Station.

Sharma, B.D., Wang, J., Brooks, J.R., Miller, G. 2010 Evaluating forest harvest strategies to enhance timber production and carbon sequestration. Manuscript prepared for successive submission to *Forest Science.*

USDA FS 2009. Forest Inventory Data Online Vers. 1.30r0. US Department of Agriculture. Forest Service. Available online at http://fiatools.fs.fed.us/fido/index.html (accessed on February 10, 2010)

USDA-FPL [United States Department of Agriculture – Forest Products Laboratory]. 2004. Fuel Value Calculator. TechLine, WOE 3. USDA Forest Producet Laboratory. State & Private Forestry Technology Marketing Unit. Madison, WI.

USDA-FPL [United States Department of Agriculture-Forest Product Laboratory]. 1953. Density, fiber length, and yields of pulp from various species of wood. Technical note 191.

USEPA [United States Environmental Protection Agency] 2009. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2007. USEPA Washington DC.

Wang, J., Grushecky, S., McNeel, J. 2007.Biomass resources, uses and opportunities in West Virginia. Biomaterials and Wood Utilization Research Center. West Virginia University, Morgantown, WV.

Widmann, R.H., Wharton, E.H., Murriner, E.C. 1998. West Virginia timber products output: 1994. Resource Bulletin NE-143. U.S. Department of Agriculture, Forest Service, Northeastern Research Station, PA.

WVPF [West Virginia Plant Fossils]. 2009. The APPALACHIAN "MOUNTAINS". Available online at http://www.geocraft.com/WVFossils/coal_rank.html (last accessed on January 31, 2009).

Zeng N. 2008. Carbon sequestration via wood burial. Carbon Balance and Management 3:1-12.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Woody Biomass Supply and Demand[1]

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Introduction

Forest biomass is one of the numerous feedstocks for the production of biofuels, biopower, and bioproducts as America embraces a renewable energy future. These woody feedstocks range from wastes in forests, at mills, and bound for landfills to purpose-grown plantations. In the middle include thinnings and the smaller-diameter merchantable wood that might be used for energy biomass depending on market conditions. Certainly, wood will continue to be sold for its highest value if markets exist.

Forisk Consulting (2010) tracks bioenergy projects across the southern U.S. that use wood and reported that there were about 130 "announced projects." The announced demand would be nearly 50 million tons per year of new wood use by 2020, although they estimated that about only half appear viable. Their projection is that nearly two-thirds will be used for electricity production (see Figure 1.).

Just last year, Oglethorpe Power (2009) announced the purchase of a site in Warren, GA for the first of two, maybe three, 100-megawatts bioenergy facilities. They go on to explain that the raw materials proposed are whole-tree chips and chipped pulpwood.

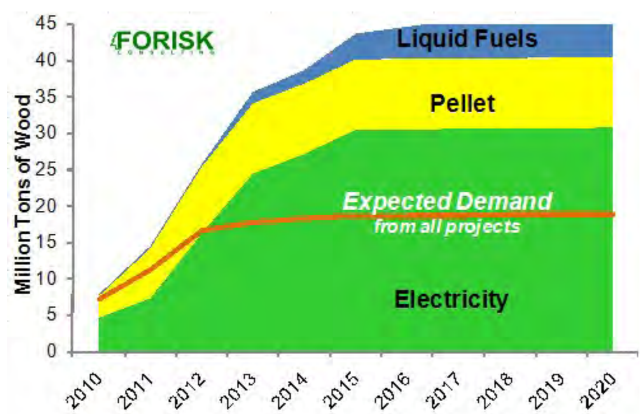

Figure 1. Estimated wood use by announced facilities in the South (Forisk, 2010).

It is expected that biomass from agricultural and forestry lands will have a significant role in our renewable energy future for electrical and heat/steam production as well as biofuels and for bio-based products. Wood is already the most significant, renewable resource outside hydro for electricity production. If the above projections and estimates from other sources materialize, wood will definitely have the dominate role in the generation of electricity and probably pellets.

This paper looks at the both the drivers of demand for wood for energy and an estimate of supply and likely impacts of increased demand. Does America have enough wood to

[1] The results and opinions expressed in this paper and by the author do no constitute or imply the policy of the Department of Energy or other federal agencies.

supply both a burgeoning biomass for energy market and still meet its demand for conventional products? It all depends on the assumptions and what actually develops in the market place.

How much biomass do we need?

Currently there are two major drivers of the use of agricultural and forestry biomass, one for biofuels and another for biopower. In addition to these, there are both congressional and executive mandates for the use of biomass in bioproducts as well as an option in the greening of buildings and operation of the government.

Biofuels Mandates and Incentives

A primary driver for biofuels has been the use of corn ethanol as an oxygenation agent with up to a 10 percent blend with gasoline. Presently that is about 14 billion gallons of ethanol per year and represents approximately 10 percent of the 140-billion-gallon U.S. gasoline market on a volumetric basis. There is discussion to increase the blend to 15 percent, but EPA has yet to make that ruling.

Another driver has been the Volumetric Ethanol Excise Tax Credit that was established in 2005 and has been extended and modified by various statutes since. It was originally a blender's tax credit for 51 cents per gallon of ethanol. The 2008 Farm Bill lowered the rate to 45 cents per gallon. Since then, there have been several other tax credits for small ethanol producers, biodiesel, small-agricultural biodiesel producers, and renewable diesel. The Farm Bill also provided a cellulosic biofuel tax credit of up to $1.01 per gallon less other credits. In addition, there have been other changes in the tax law to support the development of cellulosic biofuels.

The Energy Policy Act of 2005 established a renewable fuels standard (RFS, now sometimes referred to as RFS1) for liquid transportation fuels. The RFS was significantly expanded by the Energy Independence and Security Act of 2007 (sometimes called RFS2). The RFS requires the blending of renewable fuels (including ethanol and biodiesel) in transportation fuel. The expanded RFS mandates the use of "advanced biofuels" — fuels produced from non-corn feedstocks and with 50 percent lower lifecycle greenhouse gas emissions than petroleum fuel — starting in 2009. Of the 36 billion gallons required in 2022, at least 21 billion gallons must be advanced biofuel. There are also specific quotas for cellulosic biofuels and for biomass-based diesel fuel.

Finally, an import tariff and a most-favored-nation duty of $0.54 per gallon (for fuel use) applies to imports of ethanol into the United States from most countries. Some Caribbean countries can import duty-free which has led to some interesting transportation dynamics.

Electricity Mandates

Although there is currently no federal Renewable Electricity Standard (RES), there are 29 states and DC with Renewable Portfolio Standards in place that call for a wide range of renewable electricity standards over various time frames. Some are very aggressive and depend on projects already in place. For the southeastern U.S. where options beyond biomass are minimal, there are few states with mandates. However, as mentioned already, there are announced projects underway that include the use of wood for electricity production.

In addition to the state mandates, there has been federal legislation proposed for a national RES at various percentages, requiring up to 25 percent electricity sold by utilities to come from renewable sources by 2025. It should be noted that none have passed at this time, but the debate continues. Most interesting is that some have higher renewable energy credits for small, distributed electricity generation. In any case, it is expected that biomass and primarily wood will be one of the leaders in renewable electricity generation. Dedicated and co-firing biomass currently supplies 39 billion kilowatt/hour (0.9%) of renewable electricity to America. It is projected that in 2030, biomass will account for 231 billion kilowatt/hour (4.5%) of renewable electricity generation (AEGen Dynamics, 2009).

Wood Demand Impacts

With all these mandates and incentives, the concern is the impact on the demand for biomass, specifically wood. The Energy Information Administration (EIA) undertook a study to analyze the impacts associated with a 25 percent mandate by 2025 for both fuels and electricity (EIA, 2007). The electricity requirement is implemented as a renewable portfolio standard (RPS), while the motor fuel standard is implemented as a renewable fuel standard (RFS). The RPS results in biomass generation of 495 billion kilowatthours (363 percent) higher in 2030 under the mandate than without it. Also, about half of the required renewable generation would come from biomass. Considerable increases in biomass electricity generation occur in virtually every region of the United States. For the RFS, about 61 billion gallons are needed by 2025 of which 28 billion would be from cellulosic feedstock. This would require that biomass consumption for energy rises from less than 30 million tons in 2005 to 535 million dry tons in 2025 and almost 700 million dry tons in 2025 for the highest use scenario.

The EIA estimates that it takes about 364 million dry tons of wood to meet both mandates. This is from forest residues, urban waste, and energy crops. Sample (2009) estimated that it would take another 379 million dry tons of roundwood to meet the entire required 870 million dry tons of biomass needed annually for the mandates.

How Much Woody Biomass do we Have?

The original Billion Ton Report (Perlack, et.al, 2005) estimated that there were 368 million dry tons of wood resources available annually. This was mostly wood wastes from the forests, mills, and urban areas. It did not include the woody energy crops which were reported as "perennial crops" (either grasses or wood) that totaled 377 million dry tons. The report was just a strategic analysis and only looked at availability. It did not include costs or sustainability criteria to determine the economic and ecological availability.

For the past three years, an effort has been made to update the Billion Ton Report. It is being improved by developing cost curves for all feedstocks at a county level. This allows for an analysis of feedstocks by costs to roadside at various spatial scales with aggregation up to national estimates. It also provides land use change and acreage estimates for energy crops.

For wood, there have been changes in the types of feedstocks and the underlying assumptions as to availability primarily because of sustainability criteria and current use. Feedstocks that are already used for energy are removed – this includes almost all of the mill residues and all the pulping liquors. Also, an analysis was conducted to determine how much of the smaller diameter trees that are currently merchantable may be used for biomass with changes in the markets.

Clearly, there is no expectation that wood can supply all the biomass needs, or that we harvest vast amounts of periodic growth from our nation's forests for biomass markets. Our analysis does show that America's agricultural and forestry lands can still provide about a billion dry tons of biomass at relatively competitive cost, but probably not at current costs. The actual makeup of the feedstocks depends on many factors and will vary region to region. For forestry, there is an opportunity to increase both availability and supply, but it depends upon incentives and the markets before such actions will occur.

References

Forisk Consulting. 2010. http://www.forisk.com/Forisk-Bioenergy-Research-v-42.html

Oglethorpe Power. May 7, 2009. News Release. http://www.opc.com/Newsroom/RecentNews/ct_000471

AEGen Dynamics. September 22, 2009. http://aegendynamics.com/category/biomass-market-trends/

EIA. 2007. Energy and Economic Impacts of Implementing Both a 25-Percent Renewable Portfolio Standard and a 25-Percent Renewable Fuel Standard by 2025. August 2007, SR/OIAF/2007-05. Energy Information Administration, Washington, DC.

Sample, V. Alaric. 2009. Ensuring Sustainability in the Development of Wood-based Bioenergy in the US South. August 26-27, 2009, http://www.pinchot.org/gp/SouthRegionalMeeting

Perlack, Robert D. and others. 2005. Biomass as feedstocks for a bioenergy and bioproducts industry: the technical feasibility of a billion-ton annual supply. Oak Ridge National Laboratory, Oak Ridge, TN. 59 p.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Evaluating a Web Based Machine Productivity and Fuel Consumption Monitoring System

By

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Abstract: The Forest Operations Research Unit, Southern Research Station, USDA Forest Service is utilizing a machine productivity and fuel consumption monitoring system to remotely measure fuel consumption, productive time and geographic location of a complete harvesting system. Traditionally, fuel consumption and productivity data had to be manually collected by personnel in real time. The advancement of electronic data loggers in the last decade allowed for more long term machine monitoring, but still required periodic manual downloading. OEM Data Delivery, a division of OEM Controls, Inc. based in Shelton, Connecticut markets a machine productivity and fuel consumption monitoring system. The system collects data from individual machines via shortwave radio to a central data logger located in the foreman or crew truck. The central data logger uploads the data to the web via a cellular modem when a signal is available. The secure website can be accessed by the contractor to compile and print reports of machine utilization and fuel consumption. This paper discusses the system components and how the Forest Operations Research Unit is using it in its research.

INTRODUCTION

Measuring productivity is an essential component in evaluating and comparing forest harvesting machines and systems. Productivity can be measured using detailed or gross time study methods. Detailed time study methods are labor and time intensive and gross time study methods, although less labor and time intensive to collect data, still require cooperation and coordination with the harvesting contractor. Additionally, long term utilization and fuel consumption rates are not generally captured with detailed and gross time study methods.

Technological advances have made it possible to collect machine data using electronic data loggers and global positioning systems (GPS). To date these systems have primarily been experimental (McDonald, 1999, 2000) and even commercially available systems (Thompson, 2002) still require frequent downloading and monitoring. Machine manufacturers have begun to offer machine monitoring systems (i.e. Caterpillar's Cat Product Link and John Deere's JDLink), but these systems generally require the machine components to be electronically (computer) controlled. This requirement would not allow for older machines to be monitored.

The Forest Operations Research Unit, Southern Research Station, USDA Forest Service routinely evaluates forest harvesting activities to measure productivity and efficiency. The ability to gather machine data on multiple machines over time is essential. Over the past decade the unit has used electronic service recorders, such as the Yellow Activity Monitoring System (Thompson, 2002), and the multiple function Multidat data logger developed by the Forest

Engineering Research Institute of Canada (FERIC). Both of these devices require manual downloading of data and are not capable of measuring fuel consumption. The Forest Operations Research Unit has recently purchased a new system developed and marketed by OEM Controls, Inc. of Shelton, Connecticut. The OEM Controls, Inc. system not only offers the ability to capture machine and fuel consumption data, but also upload data to the internet. This feature will eliminate the need for the unit's personnel to make frequent trips to each operation to download the data loggers. This paper will discuss the monitoring system and how the Forest Operations Research Unit is incorporating the system into its research.

SYSTEM COMPONENTS

The Service Tracker system consists of three main components. The first is the Radio Service Tracker (RST) (Figure 1) that records machine activity. A RST is hardwired into each machine and programmed with a unique identity. The RST can also be equipped with a GPS unit to track machine movement. The RST records productive/idle time, location and, with operator input, communicates with the second system component, the Radio Pump Tracker (RPT) (Figure 2), when the machine is being fueled. The RPT receives fuel data from a fuel flow meter on the contractor's fuel truck/tank. The machine and fuel data are then gathered wireless by radio link by the systems third component, the GoPOD (Figure 3). The GoPOD is equipped with a GPS unit and a cellular modem. Data is stored and then transferred to a secure website when a cellular signal is available. The website stores and contains macros for a wide variety of data analyses, including machine utilization rates and fuel consumption.

CONTRACTOR BENEFITS

The OEM system offers multiple benefits to harvesting contractors. Machine productivity and fuel consumption data can allow a contractor to better schedule maintenance and make machine replacement decisions. Fuel tracking can identify theft of fuel. An advanced version of the OEM system secures the fuel tank and only allows authorized machines to refuel. The GPS component not only allows for the calculation of harvested areas, but also can be used to locate machines in the case of theft.

A complete system to track 4 machines (1 with GPS) and a fuel tank costs approximately $8000. The secure website, data storage and analysis capability costs approximately $3/month per machine.

Figure 1: OEM Controls Inc. Radio Service Trackers.

Figure 2: OEM Controls, Inc. Radio Pump Tracker (RPT) and fuel flow meter.

Figure 3: OEM Conrols, Inc.'s GoPOD data logger.

RESEARCH BENEFITS

The Forest Operations Research Unit has installed the OEM Controls, Inc. system on a tree length harvesting operation in central Alabama. The goal is to gain a better understanding of machine utilization and fuel consumption over time for individual machine types and the system as a whole. By utilizing the OEM system, large data sets can be gathered over a long time frame with greatly reduced personnel time and cost to collect the data.

The long term goal is to install the system on additional harvesting operations around the United States and monitor the systems on a long term basis. Long term productivity and fuel consumption data on harvesting systems working in different forest types, under different silvicultural prescriptions and in a variety of geographic locations will lead to more robust methods for estimating harvesting and machine costs at a reduced administrative cost.

REFERENCES

McDonald, Tim. 1999. Time study of harvesting equipment using GPS-derived positional data. In: Proceedings: Forestry engineering for tomorrow; 1999 June 28-30; Edinburgh, Scotland; Institution of Agricultural Engineers. 8p.

McDonald, T. P.; Taylor, S. E.; Rummer, R. B. 2000. Deriving forest harvesting machine productivity from GPS positional data. In: Proceedings; 2000 ASAE annual international meeting: engineering solutions for a new century; 2000 July 9-12; Milwaukee, WI: American Society of Agricultural Engineers; 005011. 8p.

Thompson, Jason D. 2002. Electronic service recorder for machine management. Forest Operations Review Tech. Rel. 02-R-4; Forest Operations Review (4) 1:31-32.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Biomass recovery and drying trials in New Zealand clear-cut pine plantations

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New Zealand commercial pine plantation forests are grown on a regime to maximise the recovery of higher value veneer or sawlogs. In some locations a lack of fibre market or long transportation distance can result in negative returns for the lower value logs. With log specifications that focus on quality, not quantity, radiata pine plantations generate relatively large numbers of reject logs that can include oversize logs, logs with large knots, excessive sweep or other defects. A small, but increasing, market for higher quality biomass product is developing. This includes pellets for wood burners as well as low moisture content chips for medium sized commercial boilers. Radiata pine at time of harvest typically has a moisture content (MC) of 55-60%, whereby the preferred MC for higher quality chips is less than 30%.

City Forests commenced a production focussed trial for woody biomass by stacking 1500 tons of pine logs in rows. The study location is just south of Dunedin in a location with relatively low humidity in the summer. An additional study was set up to assess moisture content change over time of stacked logs, with treatments of covered and larger logs split. The wood was stacked on pallets and weighed at approximately 1-2 week intervals. This latter study was supported by the NZ Energy Efficiency and Conservation Authority (EECA). The study showed that the larger split logs dried to 21% in 17 weeks. Small diameter logs dried more quickly than large diameter logs (23 and 32% respectively). Covering the stacks did not show to be beneficial for summer drying.

Introduction

City Forests Ltd is a major New Zealand forestry company based in the South Island that manages approximately 17,000 hectares of plantation forest. It has identified that there is the potential to further develop the regional biomass market as a carbon neutral alternative to coal. It is also a region with an overall decreasing market for other fibre-wood products. To investigate their ability to produce a larger volume of higher quality biomass chip, City Forests has stacked approximately 1500 tonnes of round-wood in the Milners Quarry for the purpose of drying and subsequent chipping. The stacks are approximately 4-6 meters wide and 4-5 meters high (Figure 1).

Figure 1: 1500 tonnes of stacked logs at Milners Quarry.

The stack consists of over sized, under-sized and other logs that do not meet sawlog grade due to defects such as sweep and knot size. Log lengths range from 2 to 6 meters. It was recognised that very little applied knowledge was available in the region as to the best option for drying the logs. Consideration was given to both covering the whole pile, and also splitting the biggest over sized logs.

There are a number of options for drying wood fibre for wood fuel: green chipping and then drying with either a blower or through the natural drying process, drying as round-wood onsite or off, and many other variations with regards to storage and drying techniques of either chips, slash or round-wood. The storage and drying of chips has shown to be problematic. Fungal and microbial activity can result in large volumes of dry matter being lost as well as very high temperatures within the piles that pose self ignition risk. Storage on an active landing is difficult due to contamination risk from dirt that significantly reduces the value of the biomass for fuel (Hall, 2009) and limited accumulation of volume for subsequent chipping (Visser et al, 2009).

Hall (2009) concluded that the best method with regard to cost of final product is one that contains as little handling steps as possible while still obtaining a fuel of adequate quality (dollars per GJ). The mass storage of round-wood lends itself well to this as handling costs are often minimised and chipping efficiency optimised.

National and international studies regarding the drying of conifer round-wood and slash has shown varied results. Climate, in terms of temperature, humidity and wind, is the most important external factor for the drying rate and final moisture content. Stacking and ensuring adequate airflow also greatly increase drying rates. A number of studies in wetter regions have found that covering has been greatly beneficial to the rate of drying of round-wood (Jirjis 1995; Kofman and Kent, 2009) due to the high risk of re-wetting caused by rain or snow. A study done recently in Wellington (New Zealand Clean Energy Centre, 2009) found that drying through the dry summer did not warrant the cost of covering, but covering the residue in the wet winter was beneficial. Needles decrease the value of the bio-fuel (Nurmi 1999) and they should be removed prior to chipping or preferably left on the site for their high nutrient content.

The purpose of this project is to determine the best and most cost effective method for air drying round-wood within the Otago region, South Island. In addition to monitoring the moisture content of the large stack trial, an experiment was set to better understand drying rates for various design options.

Methods

Moisture content

Percent moisture content (%MC) used throughout this project is wet basis. Oven dried weight was established by placing the sample in an oven at 105 degrees Celsius for 48 hours.

%MC = (total sample weight – over dried sample weight) / total sample weight.

Large Stack Trail

The 1500 tonne large stack was built up over a 2 month period over September and October 2009. The first of the chipping commenced in May 2010. That is, the total drying time was approximately 6-7 months. The moisture content of this large stack was measured by taking biscuit samples twice during the drying period, as well as measuring the moisture content of the bio-fuel chips after chipping.

Drying Study

The project design consists of three replicates each of the four described drying techniques;

1. small logs (dia < 35cm),
2. small logs covered (dia < 35cm),
3. large logs covered (dia > 35cm), and
4. large logs split and covered.

whereby these logs were stacked onto pallets and left to dry with the stack being weighed periodically in order to calculate moisture loss over time.

The logs used for this study consisted of under-sized, over-sized and reject logs between 2.5 and 4.5 metres in length. All the logs were 'fresh'; they had been harvested within just a few days prior to the study.

The delivered logs were separated into 'small' and 'large', whereby the cut-off between the categories was approximately 35 cm diameter. Half of the large logs were split prior to bucking to length; this was done with an excavator with a mounted ripping tine (Figure 2a). The log was placed up against another log resting between the tracks of the excavator and the tine pulled towards the excavator splitting the log (Figure 2b). This splitting technique proved to be both difficult and time consuming with the logs often splitting unevenly with a large proportion breaking when the tine came to a large whorl or other large defect.

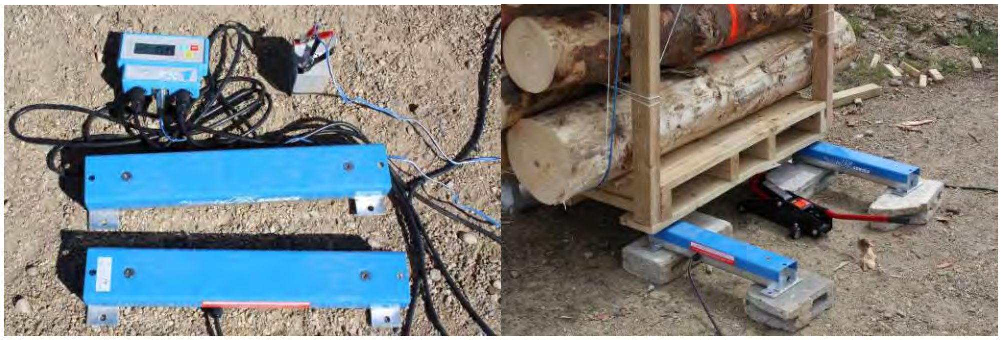
Figures 2a and 2b: The excavator, with attached ripping tine, used for the unloading, handling and splitting of the logs.

The logs were cut to a length of 1.8m. At this stage 11 biscuits were cut randomly from the logs for determining the initial moisture content.

The pallets were ordered from a local manufacturer, with minor modifications to improve strength due to the large expected weight. Wooden uprights were bolted to the pallet to safely retain the logs (Figure 3a). The pallets were then situated on top of cinder blocks to allow for ease of lifting and weighing as well as to provide a stable platform for the scales to rest on. The elevation of the pallets also stops the effect of ground moisture affecting the weight of the pallet and therefore the overall weight. The logs were carefully stacked by the loader to a height of approximately 1.6m with one trial type per pallet

Figures 3a and b: One of the 12 pallets with fitted uprights situated on cinder blocks; and pallets being loaded with logs prior to covering.

Scales were placed under the pallets to periodically measure the change in weight from which the change in moisture content could be calculated. Iconix stock scales were used, which consisted of F1X load cells and an indicator (Figure 4a). The load cells are designed to take the combined weight of both bars, with each bar consisting of two load cells. The process of weighing consisted of lifting the pallet on one side with a trolley jack (Figure 4b). The weighing data was then entered in to a spreadsheet were it was used to calculate moisture loss from the known initial moisture content calculated at the start of the trial.



Figures 4a and b: The scales, indicator and battery; and the scales placed under the pallet for weighing.

Finally, a small, medium and large diameter log was left on the landing to dry. These were laid out onto bearers to avoid ground contact. The logs were destructively sampled to check on the drying effect along the log length by cutting a series of biscuits were cut from 3 logs at 30cm intervals.

Results

Large Stack Trial

Biscuits were cut at intervals from the large stack. Testing in January (approx 4 months drying time) indicated that the MC in the ends of the logs varied quite significantly. The MC of the 8 biscuits cut ranged from 19% to 38%, with an average of 29%.

In April (approx 6 months drying time) 17 samples were taken from the main stack of wood, including biscuits from the ends as well as from the middle of the logs. Moisture content again varied considerably with a strong correlation with diameter (Figure 5), as well as middle wood versus end wood being a factor.

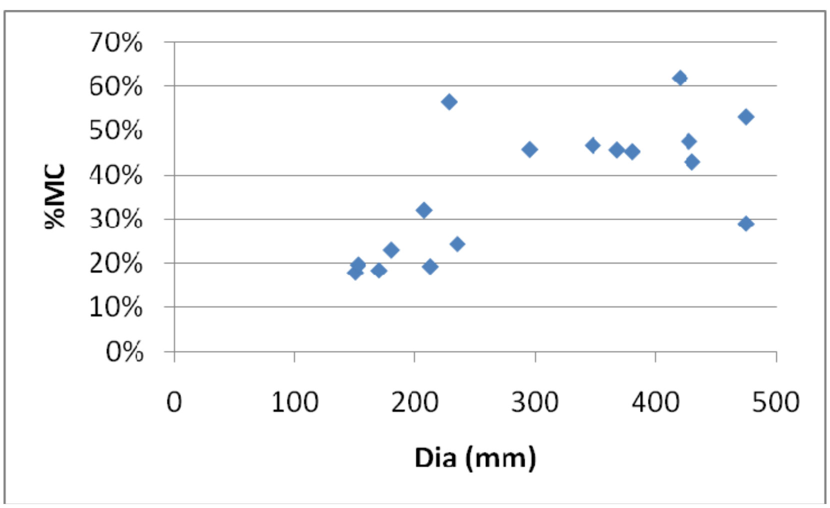


Figure 5: Moisture content results from samples taken from the main biomass stack

Overall, the average MC of the large stack was 37%. This is still quite high considering the goal was to drop the MC below 30% to achieve the higher quality wood fuel chip. However, even at 37%, the energy value per tonne would have increased from 7 Gigajoules per tonne to 11 GJ/t.

Drying Study

A series of 11 biscuits were cut from the delivered logs. MC ranged from 48 - 61% with an overall average of 53%. There was no correlation between MC and diameter, so all log stacks were considered to have a starting MC of 53%.

The stacks were weighed weekly for the first month, and then approximately at 2 weekly intervals for the remainder of the trial. The results shown in Figure 6 indicate a rapid and relatively even drying for the first 13 weeks – followed by a levelling off.

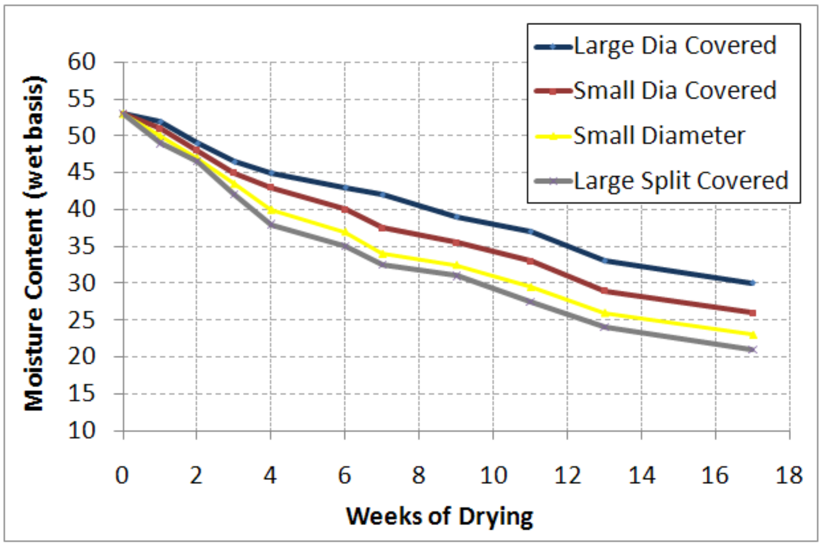


Figure 6: The moisture content for each treatment at the specified date

The large split logs dried the fastest, drying to 21% in just 17 weeks. In contrast, the large unsplit logs only dried to 30%. The small uncovered logs dried faster than those covered (23% versus 26% respectively). This suggests that while the cover would have prevented rain from wetting the logs, it may have inhibited airflow and or shaded the logs to reduce overall drying. It should be noted that it was particularly dry and hot for the duration of the study.

The main difference between the main stack trial and the pallet drying study was the average log length, as well as exposure to wind and sun. This indicates that smaller stacks of shorter logs will dry much faster. Destructive sampling of the study logs had not yet been completed at the time of writing this report to check to see if the MC estimated by weighing was accurate.

Figure 7 shows the results of the logs that were dissected (at 30cm intervals) to discern the rate of drying along the logs. There is a clear drying effect at the ends of the logs. This is consistent with the knowledge that logs primarily dry along the grain of the wood fibres, and reinforces the benefit of drying shorter logs.

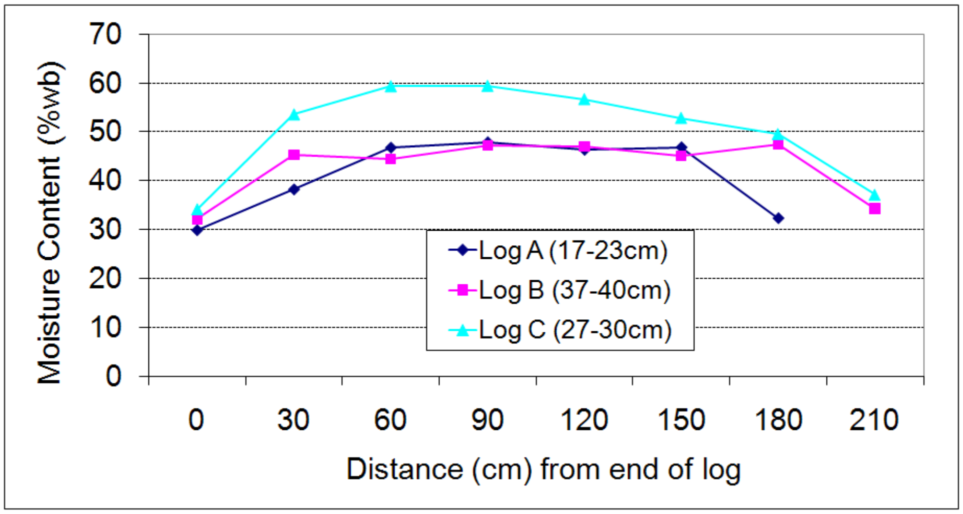


Figure 7: The moisture content along three sample logs

Conclusion

Biomass drying trials were undertaken by City Forests and University of Canterbury in summer in southern New Zealand. The overall goal was to produce higher quality chip for wood fuel. A large stack containing approximately 1500 tonnes, stacked 4 meters high, dried from approximately 55% to 37% in 6 months. While this improved energy density from 7 to 11 GJ/t, it did not achieve the intended target of 30% moisture content. A detailed study consisting of shorter logs showed that large diameter split wood dried faster than small diameter. The trial also indicated that covering the stack during summer did not improve drying rates, whereby there was minimal rainfall during the study. All of the short log stacks dropped below 30% moisture content in 17 weeks of drying.

Acknowledgements

We would like to thank the NZ Energy Efficiency and Conservation Authority for supporting this study; in particular Amber Uren (Advisor - Business) and Shaun Bowler (Program Manager Wood Energy).

Literature

Hall, P. 2009. Landing residue recovery guidlines for contractors and forest owners.
Jirjis, R. 1995. Storage and drying of wood fuel. Biomass and Bioenergy , 9, 181-190.
Kofman, P. D., and T. Kent. 2009. Storage and seasoning of conifer round-wood in the forest. Harvesting/ Transportation No.17 .
New Zealand Clean energy centre. 2009. Greater Wellington regional council forest residue utilisation trial. www.bkc.co.nz
Nurmi, J. 1999. The storage of logging residue for fuel. Biomass and bioenergy , 17, 41-47.
Visser, R. R. Spinelli and K. Stampfer. 2009. Integrating biomass recovery operations into commercial timber harvesting: the New Zealand situation. Proceedings of the Council on Forest Engineering, June 15-18th , Lake Tahoe, USA.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

LANDING SIZE AND LANDING LAYOUT IN WHOLE-TREE HARVESTING OPERATIONS IN NEW ZEALAND.

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Abstract: Landings are an integral part of modern whole-tree harvesting operations in New Zealand. A representative sample of 142 landings was measured using GPS, whereby nine were recently constructed and unused, 34 were live and the remaining 99 were older and closed out. The average landing size was 3900 m2, with a range from 1370 to 12540m2. On average, the number of log-sorts cut was 11, the landings were in use for 4 weeks, estimated daily production was 287 m3/day, 37% were manual processing (63% mechanised), 81% were grapple loader (19% front-end loader). A regression equation to model landing size indicates that number of log sorts and production levels are the two main driving factors. Landings do tend to 'grow' over time, with used landings on average being 560m2 larger than live ones, which in turn were 280m2 larger than recently constructed (unused) landings. Most recently constructed landings were larger than the company design; whereby either 40mx60m or 40mx80m were common specifications. A comparable study in 1987 showed the average landing to be just over 1900m2, indicating landing size has nearly doubled in the last 20 years. Landings serviced by front-end loaders were slightly larger than those serviced by grapple, but this is compounded by front-end loaders being more commonly used in high production systems. Analyses of the schematic drawings for the live landings indicate that as landing size grows, there is a preference for using multiple rows to manage log inventory on the landing. Smaller landings typically prefer to stack around the edge of the landings.

Keyword: Forest Operations; Processing; Landings; Skids; Timber Harvesting

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

Establishing a standard work sampling method for mastication operations analysis

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Abstract

Although mastication is increasingly used in fuel hazard reduction treatments, there is no standard method for evaluating mastication operations efficiency under various work conditions. Mastication analysis methods used in past studies vary due in part to the non-cyclic nature of mastication work in its operation. Mastication operations do not follow the same pattern or steps to complete the work, as timber harvesting activities (e.g. skidding) which have the same elements for each cycle. There is a need for a standard sampling method that may be used to accurately evaluate mastication operations efficiency at a minimum effort. This study evaluated three work sampling methods used to analyze mastication operations. Our mastication treatment occurred in northern California on gentle (5.0 to 23.5%) slopes in an area dominated primarily by shrubs such as pacific poison oak, blue blossom and coyote brush. The entire mastication operation was videotaped to allow multiple analyses using different sampling methods. All captured video was analyzed by replaying the operation at half-time (0.5x) speed to allow collection of machine activity data every 2.5 seconds. This result was used as a benchmark to compare the results of three sampling methods. We found systematic random sampling to be the preferred method. Mastication treatment costs were calculated as an example of how data from work sampling could be used to develop costs and resulted in $326.10/ac ($29.51/ton of fuel loading). We must use resources wisely to maximize contingency line construction, aiding suppression forces in their protection of wildland resources and the wildland urban interface.

Introduction

Fuel hazard reduction treatments are being increasingly used in an attempt to remedy the heavy fuel loads that cause catastrophic fire (Agee and Skinner 2005). Fire behavior is influenced by topography, weather and fuels (Rothermel 1972); we have limited control over topography and weather and therefore fuels management is our best tool to control fire behavior. Hazardous fuels treatments can be implemented in strategic areas to slow fire spread and assist suppression efforts (Finney 2001). Strategic areas are often roads and ridge tops, as they provide an intuitive contingency line to contain wildfire (Agee and Skinner 2005). In order to understand fire hazard reduction treatments more completely, many researchers have extensively studied several fuel hazard reduction methods.

One emerging tool to reduce fire hazard is mechanical mastication. Mastication changes the structure and size of fuels by shredding standing small trees and downed woody materials, leaving a mat of shredded wood on the soil surface (Jain et al. 2007). Mastication is an alternative for fire hazard reduction when the treatment area cannot be burned, mechanical removal of excessive fuels is cost prohibitive, or impacts on soil and sedimentation are of concern (Coulter et al. 2002; Rummer et al. 2003; Hatchett et al. 2006; Han et al. 2006; Kane et al. 2009).

There are a variety of methods that can be employed to analyze the cost and evaluate operational efficiency of forest operations. Among methods, the detailed time and motion study method using a stopwatch works well in evaluating cyclic activities where there is a repetitive defined course of events (Olsen and Kellogg 1983). The work sampling method is less commonly used, but can be effectively used to evaluate non-cyclic activity such as mastication (Pape 1992; Bolding 2009 personal comm.) Work sampling consists of a series of consecutive observations where the current activity of the machines is documented (Heiland and Richardson 1957; Miyata 1981; Olsen and Kellogg 1983; Pape 1992; Liao and Pape 1996; Bolding 2006).

There are certain advantages and limitations to work sampling when compared to detailed time and motion studies. Among the advantages, the most poignant include: the ability to control the accuracy by increasing the number of observations, data reduction and analysis are easier and less time consuming, and the data can often be collected by one researcher who requires less training than necessary for time and motion studies (Miyata et al. 1980). Despite the advantages, work sampling is not always correct choice as it does not record machine cycle times and may report uncharacteristic proportions if the machine cycle and observation interval coincide. Also, important events between observation times may be missed and short delays may be reported incorrectly with increase in interval length (Olsen and Kellogg 1983). Among the several work sampling methods, there is ambiguity as to which method is the best to evaluate masticators.

The objective of this study was to establish a standard work sampling method for mastication operations analysis, allowing researchers and land managers to evaluate operations efficiency and conduct fair cost comparisons. This method should aid in making informed decisions resulting in efficient use of masticators to accomplish fuels treatment objectives in a cost-effective manner. Our main approach was to compare various work sampling methods to a reference method to identify a work sampling method that provide the most accurate details on mastication operations with a minimum effort and time.

Methods

<u>Study sites and mastication treatments</u>

Mastication for fuel hazard reduction was implemented at Humboldt State University's L.W. Schatz Demonstration Tree Farm, located near Maple Creek in northwestern California. Steep topography and availability of brush fields limited the area suitable for operation to nine small units of similar slope and fuel load conditions (Table 1). The areas selected were dominated primarily by a dense cover of shrub species such as pacific poison oak (*Toxicodendron diversilobum* (Torr. & A. Gray) Greene), blue blossom (*Ceanothus thyrsiflorus* Eschsch.), and coyote brush (*Baccharis pilularis* DC.).

Table 1. Site characteristics of nine units for mastication treatment.

Unit #	Treatment size (ac)	Ground slope (%)	Fuel loading (ton/ac)
1	0.75	23.5	11.04
2	0.35	5.0	7.42
3	0.25	17.5	9.60
4	0.70	22.0	18.04
5	0.60	14.5	14.50
6	0.72	9.8	7.64
7	0.35	12.5	8.52
8	0.26	15.0	10.37
9	0.48	17.5	12.32

A small scale masticator with an integrated horizontal drum type masticating head was employed to reduce the hazard of the fuels as our desired outcome was a mulched fuelbed; the horizontal drum masticators are more effective at producing this effect than the rotary type (Windell and Bradshaw 2000). The base machine was an ASV RC-100 rubber-tracked carrier with the masticating head (FECON Bull Hog SS) attached to the front-end of the base machine. The total weight of the carrier and head was 13,400 lbs, resulting in ground pressure of 3.5 psi. The total width of the machine was 87 in.; the total length was 148 in. with 14 in. of ground clearance; the small size of this machine makes it a viable option for small areas such as our study. Large equipment becomes cost prohibitive when treating areas of fewer than ten acres (Cubbage 1983) so we chose a small machine to conduct the treatment.

Data collection

Evaluation of three work sampling methods

To estimate the fuel loading of the treatment areas, this study employed the use of the generalized fuelbed depth to fuel load equation for masticated fuelbeds developed by Kane et al. (2009). Slopes were measured from boundary to boundary on cardinal direction axes and averaged to obtain a mean slope. The size of each treatment unit area was measured using a Trimble GeoExplorer XT GPS unit.

To compare work sampling methods, we videotaped the entire operation using a Canon XL1S digital video camcorder. After the treatment, the video was slowed and sampled (Table 2) to a nearly continuous level (2.5 second fixed interval) in order to establish a benchmark against which the different sampling procedures were compared. The operation was then sampled using three different methods of work sampling (Systematic Random Sampling, Simple Random Sampling, and Stratified Non-Continuous Sampling) to evaluate which is the most accurate and most easily implemented (Pape 1992). These methods were selected using a dichotomous key for selection of the proper industrial engineering work sampling method (Pape 1992). The translation from industrial engineering into forest operations introduced some ambiguity as to which of the three possibly appropriate methods was the best and were tested to find supporting evidence.

Table 2. Work sampling consists of several “snapshot” observations where the activity of the machine was recorded as being one of the listed items. Productive and delay elements were the major categories of further interest as this yields the delay ratio, an important factor in determining operational efficiency. Research delay is separated from the rest as inclusion of this delay is not representative of non-research work conditions.

Operations action category	Sub-categories of operations actions
Productive elements	Masticating standing material (vertically oriented and intact vegetation)
	Masticating downed material (vegetation not intact and not vertically oriented)
	Traveling
Delay elements	Operational delay[1]
	Personal delay[2]
	Mechanical delay[3]
Research Delay	Research delay
[1] Delay that contributes to productivity of the operation [2] Delay such as resting, eating or breaks [3] Delay involving machine maintenance or care	

The number of work sample observations required for the desired confidence limit and relative accuracy was determined from the following equation (Miyata et al. 1981):

$$N = \frac{Z^2 Q}{E^2 D} = \frac{(1.64)^2(1-0.113)}{(0.10)^2(0.113)} = \frac{2.38567}{0.00113} = 2111.22 \approx 2111$$

Where:
N= number of observations (sample size)
Z = a normal deviation which depends on the confidence level selected (confidences of 90, 95 and 99 percent yield Z values of 1.64, 1.96 and 2.57 respectively)
Q = (1 – D) percentage occurrence of non-delay expressed as a decimal
E = desired relative accuracy expressed as a decimal
D = percentage occurrence of delay expressed as a decimal (normally estimated from prior studies, the figure used in this study is the actual calculated delay ratio from the benchmark dataset).

The confidence limit and relative accuracy for this study followed Miyata et al. (1981) and were set at 90% and 10%, respectively. These values were chosen due to the variability of forest operations where confidence limits of 99 to 95% and relative accuracy of 5% require an often prohibitively large number of observations (Miyata et al. 1981).

The delay ratio for the masticator was calculated from the work sampling data and provides the inverse of the utilization rate (amount of time the machine spends actually working, expressed as a percent). The delay ratio was calculated as follows:

$$Delay\ ratio = \frac{Number\ of\ observations\ of\ delay}{Total\ number\ of\ observations}$$

Systematic Random Sampling (SyRS) is conducted by calculating a fixed interval length with a random start time within the first interval then repeated sampling at the fixed interval length for the duration of the study (Bolding 2006). The interval length is calculated as such (Pape 1992):

$$Fixed\ interval = \frac{t}{r} = \frac{t}{N} = \frac{971.96}{2111} = 0.46\ min. \approx 27.6\ seconds$$

where:
t = minutes of study duration (can be estimated or calculated after the fact as in video analysis)
r = the number of observation "rounds" (for a study of only one person or machine the number of "rounds" equals the number of observations, thus $r = N$)

Simple Random Sampling (SRS) simply dictates that the researcher randomly select *N* times without replacement from the total population of times, *t* (Moder 1980). There are a number of ways to generate random times such as random number generators as well as random number tables (Heiland and Richardson 1957; Miyata et al. 1981; Pape 1992).

Stratified Non-Continuous Random Sampling (StNCRS) is more complex than the prior two methods since it requires that observation times encompass different times and days as a means of reducing variance (Moder 1980; Pape 1992). Observation times are randomly selected within each of the fixed intervals (t / r, in this study 27.6 sec.). No special consideration for stratification was necessary for this study as the dataset spanned several days and times.

Data analysis

The delay ratio resulting from the three different sampling methods was tested against the benchmark method to evaluate their accuracy. A 2-proportion test for difference (using the normal distribution to approximate the binomial distribution) was conducted three times, once for each of the selected work sampling methods. This analysis tested the null hypothesis that the difference between the benchmark and the work sampling method is equal to 0, but did not compare the different work sampling methods to each other. The tests were run using an alpha level of 0.01667 so that we could be 95% confident in all three conclusions simultaneously (0.05/3 = 0.01667). We hypothesized that at least one of the delay ratios would differ from the benchmark delay ratio.

The average hourly cost of operating this machine was calculated using standard machine rate methods (Miyata 1980; Brinker et al. 2002). Work sampling provided the utilization rate used in the standard machine rate calculation to obtain cost per productive machine hour (PMH) and was then be translated into production rate and various cost expressions according to the following cost tree diagram (Figure 1).

Figure 1. This cost tree diagram illustrates the process whereby collected data are calculated to determine the mastication cost.

Results and Discussion

Evaluation of three work sampling methods

The mastication operation yielded 16 hours of machine operation, resulting in 23,325 observations for the benchmark and 2,111 observations for each of the three work sampling methods that were evaluated. There was strong evidence that none of the work sampling delay ratios were significantly different from the benchmark ($p > 0.01667$; Table 3).

Table 3. The results for the three separate 2-proportion tests for difference show that none of the work sampling methods produced a delay ratio that was significantly different from the benchmark.

Sampling method	Delay ratio (proportion)	Estimate for difference from benchmark	98.33% CI[1] for difference from benchmark	p-value	Different from benchmark
benchmark	0.113				
SyRS[2]	0.114	-0.001	(-0.018, 0.016)	0.873	No
SRS[3]	0.116	-0.003	(-0.021, 0.014)	0.625	No
StNCRS[4]	0.123	-0.010	(-0.027, 0.008)	0.180	No

[1]Confidence Interval, 98.33% because alpha level set at 0.01667 for 95% family-wise confidence in all three conclusions simultaneously ($\alpha = 0.05/3 = 0.01667$)
[2]Systematic Random Sampling
[3]Simple Random Sampling
[4]Stratified Non-Continuous Sampling

As there was no significant difference in the accuracy of the sampling methods, the strengths and limitations of each were evaluated to establish which is the most easily implemented. Drawing sample times was the easiest using SyRS, followed by SRS and lastly StNCRS. Our conclusion was also supported by the findings from Pape (1992).

Work sampling can be mentally fatiguing (Olsen and Kellogg 1983), so it is important to select a method where collecting observations is easy. In this regard, the preferred method was SyRS, followed by StNCRS and lastly SRS (Pape 1992). SRS was judged to be the most difficult in this category because by random chance there might be a cluster of many sampling times; this may result in insufficient time between observations to realize what the machine is doing before the subsequent observation (Miyata et al. 1981; Olsen and Kellogg 1983; Pape 1992). By combining the outcomes of these ease of implementation measures SyRS was shown to be preferable, as was also found by Gardner and Schillings (1969). Despite this conclusion, there are dangers to SyRS.

The primary caution to work sampling is that important events between observations can be missed, especially as the interval between observations becomes longer. This may be overcome with short intervals such as Bolding's (2006) use of a 20-sec. interval or the 30-sec. interval recommended by Olsen and Kellogg (1983). However, deviating from the calculated interval length may result in unequal sampling; this may result in bias (Pape 1992).

Using SRS, the sixteen hours of video were used to analyze the productivity of the masticator. The masticator's operation yielded 11.3% delay, 85.7% productive, and 3% research delay. The delay and productive categories were further divided to assess how often the machine engages in the elements within these categories (Figure 2).

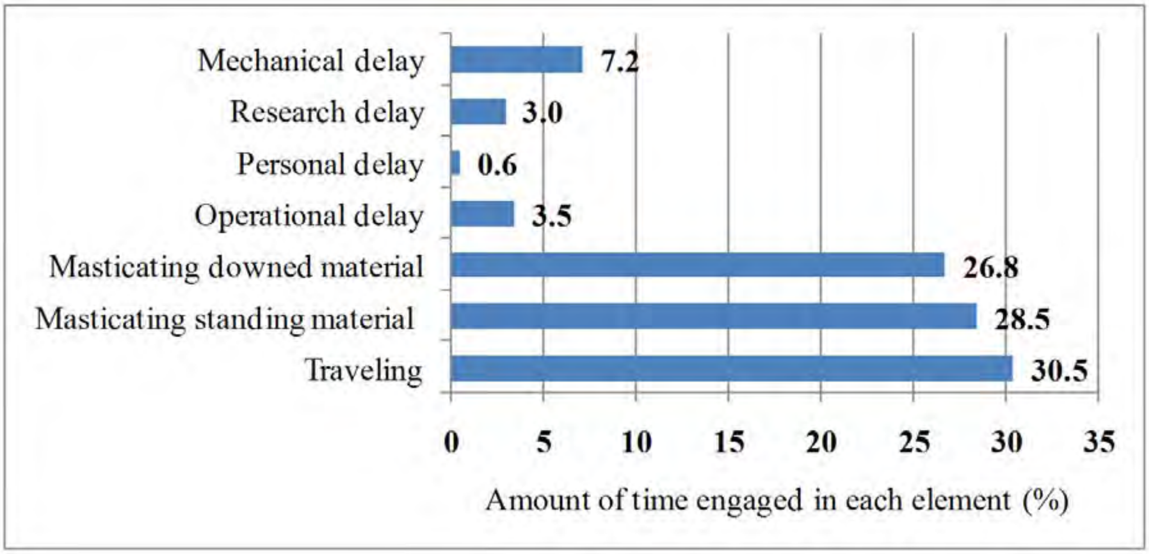

Figure 2. Using Systematic Random Sampling, the masticator's activities were divided into productive and delay categories as well as separating the research delay. Productive time was divided into its elements: traveling, masticating standing material and masticating downed material. Delay time was also divided into its elements: operational delay, personal delay and mechanical delay.

This machine used an integrated (front-end attached) horizontal drum type masticator, review of existing literature shows similar percentages for similar machines but vastly different percentages for boom-mounted rotary type masticators. Bolding (2006) showed that these machine types differ significantly ($p<0.05$) in activity proportions in nearly every category. Our results as well as those from Bolding (2006) and Halbrook et al. (2006) show integrated masticators having a vastly higher percentage of time traveling than the boom-mounted type; this difference is most likely resulting from the fundamental difference in the ways these machines operate. Integrated machines must travel to force the masticator into the material to shred it, but boom-mounted masticators may remain stationary and swing the boom to the material to be shredded.

<u>Cost analysis of mastication treatments</u>

The machine operated for 16 hours over five days, treating 4.46 acres with a utilization rate of 85.7%. The production rate for the machine was 0.32 ac/PMH with an operating cost of $106.07/PMH, yielding a cost of $326.10/ac. The average fuel loading across all units was 11.05 tons/ac. Using this information the calculated cost for the mastication treatment was $29.51/ton.

In forest operations there are some variables that are difficult to measure for a controlled study but directly and indirectly affect machine operations efficiency. We have performed a sensitivity analysis to see how changes in production rate (ac/PMH) and utilization rate affect the total cost of the mastication treatment operation (Figure 3). The cost for this machine appears to be more sensitive to changes in production rate and robust against changes in the utilization rate, especially at higher production rates.

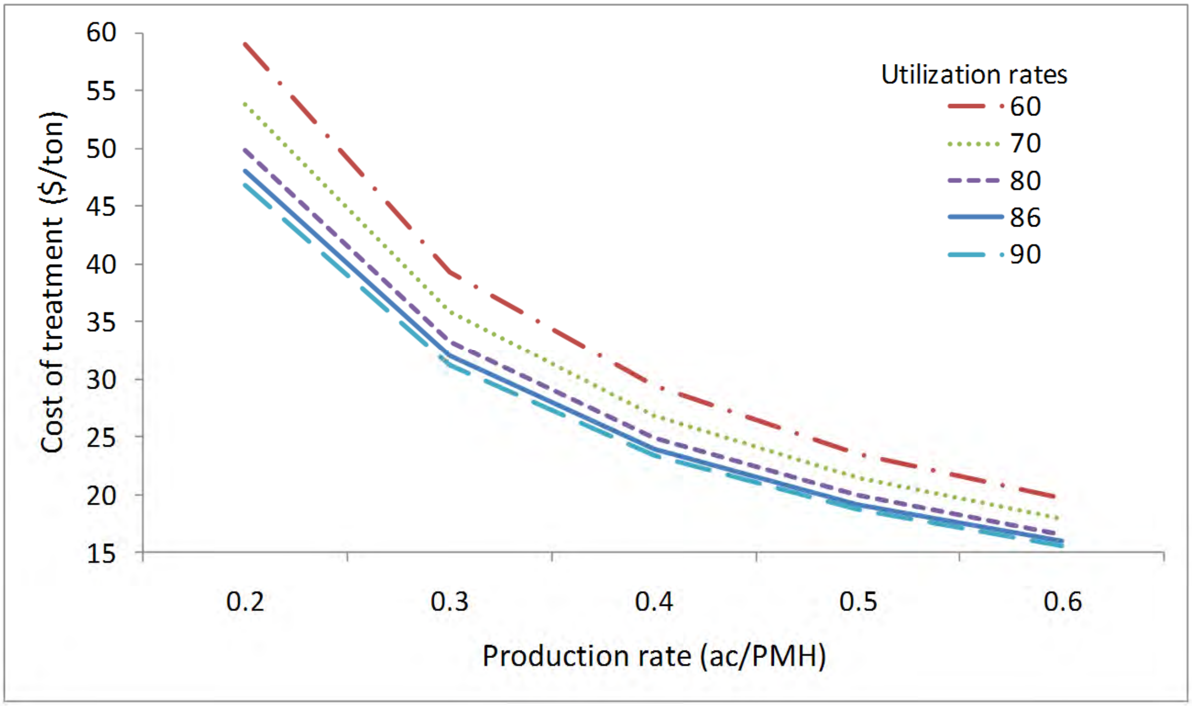

Figure 3. Effect of various production rates and utilization rates on the overall cost of the mastication treatment**.**

The methods described should serve as a guide for land managers to approximate treatment costs. These estimates were developed from the treatment of areas that were dominated by relatively light fuel loading primarily comprised of shrub species. Extrapolating these figures to areas dominated by heavier fuel loading and different vegetation is not advisable as the variables that affect cost in those situations may be different. That said, the costs observed in this study were within the range of mastication costs ($100-1395/ac) and comparable to those found by other studies (Vitorelo 2009). The lower production rate of small machines is offset by low initial purchase price, yielding costs similar to that of the larger machines. For example, Bolding (2006) reported the cost for a similar machine type of $27.74/ton, and $24.97/ton for a boom-mounted machine.

Conclusions

This study of an integrated horizontal drum type masticator in northwestern California yielded useful results. The evaluation of the three work sampling methods established systematic random sampling as the preferred method for mastication operations analysis based on ease of implementation as the lack of difference in accuracy among the three different methods. Work sampling allows calculation of productivity rate which is crucial as productivity was shown to have strong influence on treatment cost. Cost analysis was included in this paper to serve as an example of how work sampling data can be used to calculate the operating costs of masticators. While the presented study represents a local case study, these results are valuable in the context of existing literature as the costs are within the established range and the costs of small scale machines are poorly documented.

Additional research is necessary to expand the inference of this work in both work sampling method establishment and the associated cost analysis. The use of different machines, both horizontal drum and rotary masticators, across a diversity of vegetation types, slope and fuel loads will allow broader use of these results by land managers and researchers.

Land managers would find greater ease in evaluating fuel hazard reduction options with increased knowledge of associated costs and consistent evaluation methods. If researchers employ the standard work sampling method established here there can be valid comparison of the cost estimates produced. Valid comparison will yield greater precision in cost estimation, ultimately leading to wiser use of finite fuel hazard reduction funding and treatment of more high risk areas. The increasing number of high severity fires and their tremendous costs dictate our call to action. We must use resources wisely to maximize the amount of area treated, aiding suppression forces in their protection of wildland resources and the wildland urban interface.

References

Agee, J.K. and C.N. Skinner. 2005. Basic Principles of forest fuel reduction treatments. For. Ecol. Mgmt. 211: 83-96.

Bolding, M.C. 2006. An Integrated Study of Mechanical Forest Fuels Reduction: Quantifying Multiple Factors at the Stand Level. Doctor of Philosophy Dissertation. Department of Forest Engineering, Oregon State University, Corvallis, OR. 368p.

Bolding, M.C. 2009. Personal communication. Assistant Professor of Forest Operations and Engineering, Virginia Tech Department of Forestry, Blacksburg, VA.

Brinker, R.W., J. Kinard, B. Rummer, and B. Lanford. 2002. Machine rates for selected forest harvesting machines. Circular 296 (revised). Alabama Agri. Exp. Sta. 29 p.

Coulter, E., K. Coulter, The Yankee Group, Inc., and T. Mason, TSS Consultants. 2002. Dry Forest Mechanized Fuels Treatment Trials Project. Final Report. 92p. Available online at: www.fs.fed.us/vegtools/techniques/mechanical.shtml.

Cubbage, F.1983. Economics of forest tract size: Theory and literature, U.S. DA, Forest Service Gen. Tech. Rep. SO-GTR-41. Southern Forest Experiment Station, New Orleans, LA. 21p.

Finney, M.A. 2001. Design of regular landscape fuel treatment patterns for modifying fire growth and behavior. For. Sci. 47(2): 219-228.

Gardner, R. and P.L. Schillings. 1969. Efficiency of tree data-gathering methods for study of log making activities. USDA Forest Service Research Note INT-100. Intermountain Forest and Range Experiment Station, Ogden, UT.

Halbrook, J., H-S. Han, R. Graham, T. Jain, R. Denner. 2006. Mastication: A fuel reduction and site preperation alternative. Proc. July, 2006 Council On Forest Engineering (COFE) meeting, Coeur d'Alene, ID.

Han, H.-S., D. Page-Dumroese, S.-K. Han, J. Tirocke. 2006. Effects of slash, machine passes, and soil moisture on penetration resistance in a cut-to-length harvesting. Int. J. For. Engin. 17(2): 11-24

Hatchett, B., M. Hogan, M. Grismer. 2006. Mechanical mastication thins Lake Tahoe forest with few adverse impacts. California Agriculture 60(2): 77-82.

Heiland, R.E. and W.J. Richardson. 1957. Work Sampling. York, PA, the Maple Press Co.

Jain, T., R. Graham, R. Denner, J. Sandquist, J. Evans, M. Butler, K. Brockus, D. Cobb, D. Frigard,H-S. Han, J. Halbrook. 2007. Restoration of Northern Rocky Mountain Moist Forests: Integrating Fuel Treatments From the Site to the Landscape. Published in: Deal, R.L., tech. ed. 2008. Integrated restoration of forested ecosystems to achieve multiresource benefits: proceedings of the 2007 national silviculture workshop. Gen. Tech. Rep. PNW-GTR-733. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. 306p.

Kane, J.M., J.M. Varner, and E.E. Knapp. 2009. Fuel loading in mechanically masticated fuel beds in northern California and southwestern Oregon, USA. International Journal of Wildland Fire. 18: 686-697.

Liao, P.-Y., and E. Pape. 1996. Fixed-random mixture method for work sampling. IIE Transactions 28: 713-721.

Miyata, E.S., 1980. Determining fixed and operating cost of logging equipment. General Technical Report NC-55. USDA Forest Service, North Central Forest Experiment Station. St. Paul, Minnesota. 16p.

Miyata, E.S., H.M. Steinhilb and S.A. Winsauer. 1981. Using work sampling to analyze logging operations. USDA Forest Service, Research Paper NC-213, 8p. USDA Forest Service, North Central Forest Experimentation Station, St. Paul, MN.

Moder, J.J. 1980. Selection of work sampling observation times: part I – stratified sampling. AIIE Transactions. 12(1): 23-31.

Olsen, E.D., and L.D. Kellogg. 1983. Comparison of time-study techniques for evaluating logging production. Transactions of the ASAE 26(6):1665-1668, 1672.

Pape, E. 1992. Work Sampling. In: Salvendy, G. 1992. Handbook of Industrial Engineering, Second Edition. New York, Wiley & Sons, Inc. p.1699-1721.

Rothermel, Richard C. 1972. A mathematical model for predicting fire spread in wildland fuels. Res. Pap. INT-115. Ogden, UT: U.S. Department of Agriculture, Intermountain Forest and Range Experiment Station. 40 p.

Rummer, B., J. Prestemon, D. May, P. Miles, J. Vissage, R. McRoberts, G. Liknes, W.D. Shepperd, D. Ferguson, W. Elliot, S. Miller, S. Reutebuch, J. Barbour, J. Fried, B. Stokes, E. Bilek and K. Skog. 2003. A strategic assessment of forest biomass and fuel reduction treatments in western states. Gen. Tech. Rep. RMRS-GTR-149. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 18 p.

Vitorelo, B., H-S. Han, and J.M. Varner. 2009. Masticators for fuel reduction treatment: equipment options, effectiveness, costs, and environmental impacts. Proc. 2006 Council On Forest Engineering (COFE) meeting, Lake Tahoe, CA. 11p.

Windell, K.and S. Bradshaw. 2000. *Understory biomass reduction methods and equipment catalog.* Tech. Rep. 0051-2826-MTDC. Missoula, MT: USDA Forest Service, Missoula Technology and Development Center. 256 p.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

The effect of harvesting system on forest residue production in Fiji

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Abstract

Pacific Island Countries including Fiji have large tract of forest areas and plantation forestry mainly for log production. With the current increases in world oil prices and Fiji's dependence on oil for its transport and energy sector, Fiji is looking at renewable energy sources from forest biomass to minimise reliance on oil for energy production and also to utilise forest residues arising from annual harvesting operations.

Fiji's current harvesting system is mainly semi-mechanised with manual felling, delimbing and conversion. Rubber tiered skidders are mainly used for tree hauling from the cut-over areas to the landings although in native forest logging tracked bulldozers are used. Current log supply volume form the forest totals to 300,000 tonnes per annum and is expected to increase to 500,000 tonnes from 2010. Fiji Pine Limited, the owners of the plantations, also see forest biomass sale as a source of revenue especially with the planned increase in log supply volume.

Independent power producers will soon be demanding biomass for their renewable energy production. This research will compare conventional with integrated harvesting on *Pinus caribaea* plantations, establishing production estimates and costs for biomass supply. This research is to be undertaken for a PhD degree at the University of Canterbury in Christchurch, New Zealand. The forest residue production research based on commercial harvesting operations will be the first to be conducted for Pacific Island Countries and hence it is hoped the research findings can be widely applied.

Introduction

Pacific Island Countries and States (PICS) face a number of unique challenges to their pursuit of sustainable development, foremost among these challenges is the high dependence upon imported energy sources. Ironically, these countries like Fiji have considerable water and forest resources for renewable energy sources. Fiji, like many other small developing countries, used to depend almost totally on imported oil (95% in 1981) to satisfy its commercial energy requirements. With the completion of a hydro dam in 1982 and Independent Power Producers (IPPs) starting to produce power, Fiji's reliance on fossil fuel has decreased (34% in 2008). Even though electricity from diesel generation has decreased in 2008, the fuel price has increased by five and seven percent in 2007 and 2008 from the 2006 figures when 42% of electricity was generated from diesel generation. With droughts occurring frequently in Fiji, industrial diesel generators still play an important role in the production of power in the country hence Fiji's dependence on fossil fuel remains despite increase in world oil prices (Figure 1).

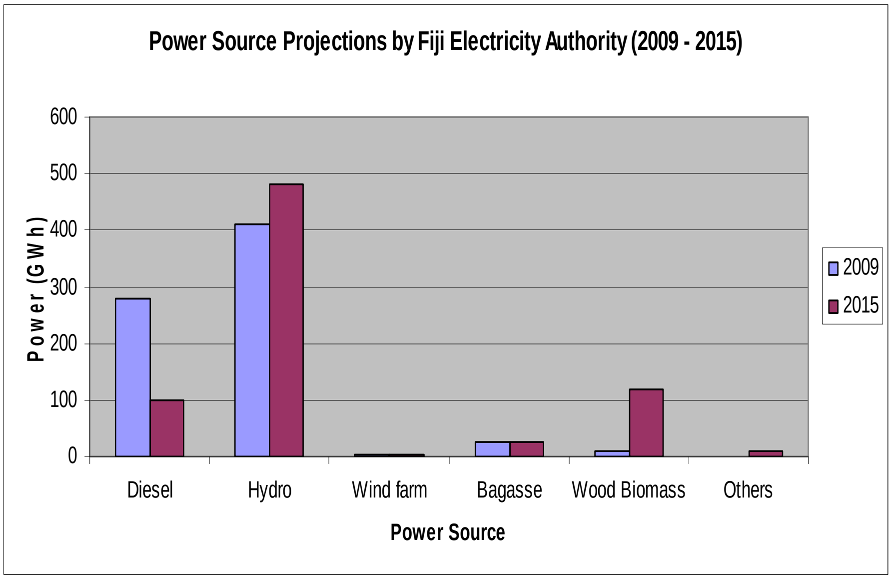

Figure 1: Fiji's energy: comparing current supply with projected for 2015. Note the intended increase in energy coming from biomass.

The Fiji Department of Energy (DOE) is promoting renewable energy sources as a viable commercial electric generation option (DOE, 2006). The biomass power industry has a promising future, especially with recent and proposed regulatory changes in the development of Fiji's National Energy Policy and Fiji government's budget incentives announced in 2009 and 2010 that will look at renewable energy sources for the electricity market. (MFNP, 2009). There is a need to take advantage of these regulatory changes, as IPPs can play a major role to produce electricity through the use of an alternative energy source such as woody biomass.

Fiji Electricity Authority (FEA) forecasts an annual growth in power consumption of 5-6% per annum thereby an annual production capacity of 1,200 MW by 2025. FEA has also indicated in its mission statement of producing 90% of power from renewable energy sources by 2015 and expects power production from wood biomass to increase from the current 1% to 16% of the total power production by 2020 (FEA, 2009). This has implications to forestry companies and other wood growers that there will be an increased demand for wood biomass in the future.

The feasibility of a bio-energy project is highly dependent on the availability of biomass. This has implications to forestry companies and other wood growers that there will be an increased demand for wood biomass in the future.The feasibility of a bio-energy project is highly dependent on the availability of biomass. In other words, in order to keep a bio-energy facility in operation over its lifetime, the quantity of biomass supplied should meet the quantity of biomass demanded by the facility.

New Zealand estimates that to meet its bio-energy demands by 2050, it would need to establish 2.5 to 2.8 million hectares of energy forest plantations (Hall et al, 2008). Calle and Woods (2003) undertook individual biomass resource assessment profiles for the Pacific Island Countries including Fiji and highlighted the fact that considerable fieldwork is required to determine the biomass levels because of the non-availability of data. Calle et al. (2003) also noted that forestry residues were poorly utilised and there was a potential for forestry biomass in Fiji to be a source of bio-energy production.

Forest biomass from forest management is a renewable, carbon feedstock that can substitute for fossil fuels in the production of energy and other products (Caputo, 2009). In forest industries, biomass is a product of forest management practices applied during the growth of a stand such as pruning and thinning, are normally termed as silvicultural residues (Puttock,1995; Malinen et, al. 2001; Richardson et al, 2002). In commercial harvesting operations, low quality stems, branches, treetops, stumps and root systems are referred to as logging residues (Puttock, 1995, Richardson et al 2002). Silvicultural and logging residues are called forest residues. Wood residue is produced from the processing or breakdown of logs and/or round wood into sawn timber or other wood products (Figure 2). Common wood residues produced from primary processing include: bark, slabs, sawdust, chips, coarse residues, planer shavings, peeler log cores, and end trimmings. Secondary manufacturers typically produce the following types of wood residues: chips, sawdust, sander dust, end trims, used or scrapped pallets, coarse residues and planer shavings. Coarse residues, for both manufacturing groups, include slabs, edgings, trims and cores.

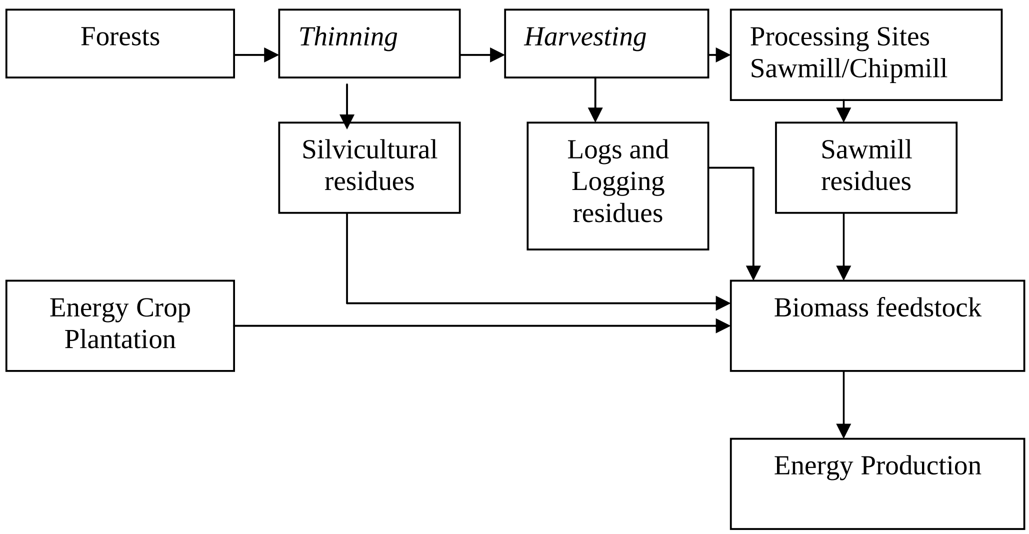

***Figure 2**: Sources of biomass in forestry*

Economic factors affecting the supply of forest biomass include production costs, prices of biomass and its substitutes, competing uses of forest resources, and policy, among others (Hamelinck et.al, 2005). First, technologies for forest production, biomass harvest and transport, and energy conversion will dictate the production costs of forest biomass and bio-energy. Thus, research and development will have an important role to play in forest biomass and bio-energy development. The costs will also vary with scale of operation, biomass spatial density, terrain conditions, average stem diameter, and transport distance, among other things. The most cost-effective production of biomass for energy occurs when it is produced simultaneously with other higher valued forest products (saw logs, pulp logs).

Capital investment in biomass production is quite intensive and in the case of Fiji, current investments on logging machines are mostly restricted to purchase of second hand machines from New Zealand and Australia. The volume and quantum of biomass operations will also dictate the capital investment in the PICs. Current interest rates in Fiji on business loans are between 13 – 15% (RBF, 2009) compared to 6-9% in New Zealand (ANZ, 2009) hence costs of biomass production are affected.

Harvesting of Biomass

The biomass supply chain is made up of a range of different parties including forest owners (individual/companies), contractors, transport and distribution companies and customers. Poor decisions relating to the choice of harvesting, transport and processing equipment, or poor matching of the various components of the fuel supply chain, can lead to unacceptably high costs and unacceptable fuel quality (Sims, 2005).

The current method of log harvesting in the study area involves partial trimming of logs and topping off at the cut-over area with final trimming and log conversion in the landings (Figure 3).

Figure 3: Four photos showing typical harvesting operations in Fiji

There are different methods of harvesting logging residues. Puttock (1995), Hudson (1995), IEA (2007) suggest the integrated harvesting approach where energy and conventional forestry products are harvested simultaneously in a one pass harvesting operation mainly because the method offers potential for reducing harvesting costs. Hudson (1995) identifies the cost reduction from the method because forest residues are by-products of the production of conventional forest products thus it is assumed that the forest residue production is available at zero cost.

In developed countries, integrated harvesting has gone through improvements to minimise costs. Scandinavian countries have modified systems to handle cut-length harvesting residues using chippers, bundling (Baker et al, 2010). Some USA states have modified system by adding chipper (Green et al., 2007). While Visser et al (2009) suggest options to process residues and transport as chips or bundle and transport to stationary chipper for processing in New Zealand.

Baker et, al. (2010), Stuart et, al. (1981) and Desroches et al. (1994) view that the production cost should be shared between the conventional forest products and forest residue based on some appropriate percentage. Other benefits from residue recovery includes the reduction in detrimental environmental effects arising from accumulation of forest residue materials, as whole tree processing ensures minimum accumulation of residues and ease of silvicultural operations for next rotation (Puttock, 1995). Integrated harvesting systems also reduce forest fuel level at harvesting sites (Han and Johnson, 2004).

This study will investigate the potential use of wood biomass energy resources arising from harvesting operations and energy wood plantations. The future generation of commercial electricity from wood biomass would increase the utilization of wood and forest residues from FPL resources. A model will be developed to determine the forest residue levels arising from different harvesting systems and the economics benefit of wood biomass sale to forest growers.

The objectives of the study are:

1. To understand how different harvesting systems impact on residue (cutover and landing) volumes and the costs related in collection and transportation of residues.
2. To develop a robust model that will predict biomass volumes and delivered costs from harvesting residues and energy wood plantations.
3. To use these results in an estate level case study to evaluate the economic benefits to the forest grower of biomass supply options.

Methods

The methodology developed for this study estimates the theoretical and available biomass potential. The model that will be used in the estimation of the forest residue, log volume and energy wood component of the study is illustrated in Figure 3. The model is a mathematical model using MARVL and EXCEL software for the forest residue component, LIRO software for the harvesting system. The model will ensure the validation of potential biomass volume by undertaking field data collection on cut-over and landing residues.

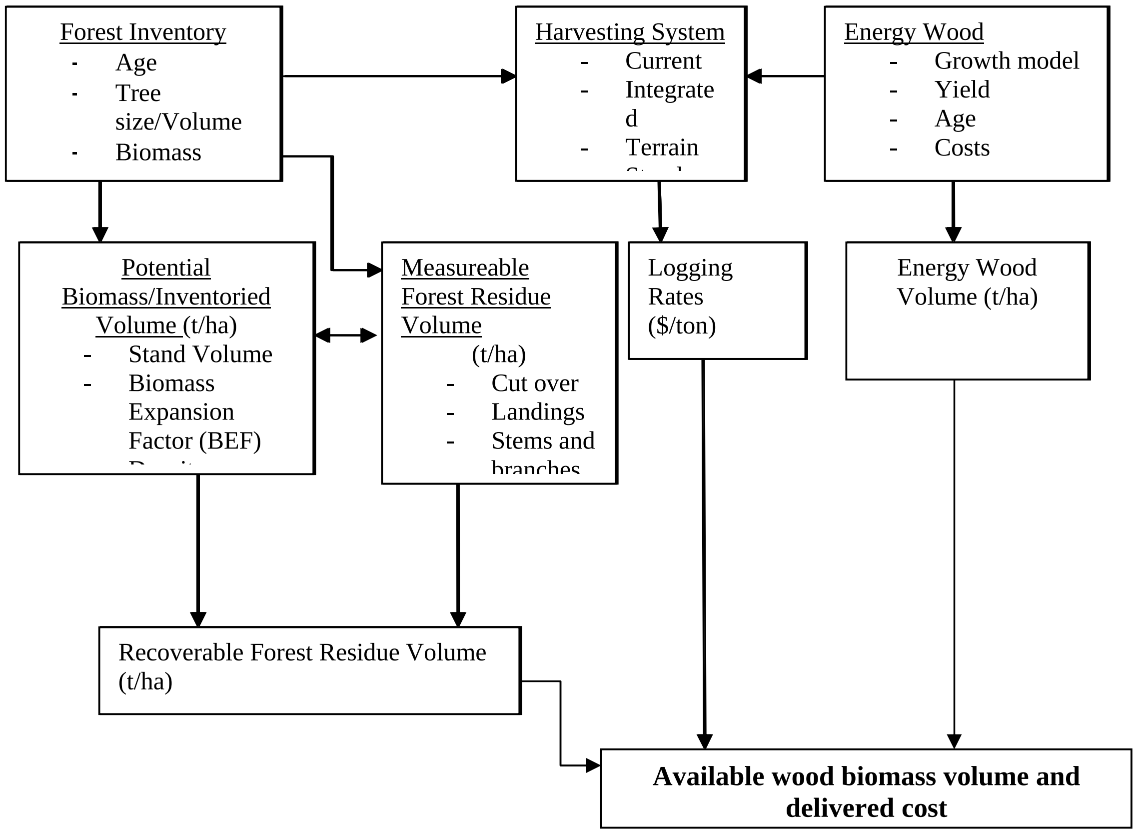

Figure 4: *Illustration of forest biomass model*

Summary

The key question of the research is will focus on how much biomass can be mobilized in a sustainable and cost-effective way from harvesting residues and energy wood plantations. The research will assess the technical and economical aspects of wood biomass production and supply of wood biomass for bio-energy production. The model will be tested on a Fiji case study.

The research will be expected the following on new information for wood biomass:

i. Forest residue production of two different semi mechanised harvesting system common in the Pacific islands compared to mechanised systems in developed countries.
ii. Development of biomass allometric equations and growth model for Acacia *mangium* in Fiji.

References

ANZ Bank http://www.anz.co.nz/ratefee/interest.asp accessed 1 Nov 2009.

Baker, S.A; Westbrook, M.D; Greene,W.D (2010) Evaluation of integrated harvesting systems in pine stands of the southern United States. Biomass and Bioenergy (In press). 2010. Doi:10.1016/j.biombioe.2010.01.014. 8 pages.

Calle, F.R and Woods (2003) Individual Country Biomass Resource Assessment Profiles for Fiji, Kiribati, Samoa, Tonga, Tuvalu and Vanuatu. SOPAC Technical Report 364. Prepared for South Pacific Applied Geoscience Commission (SOPAC).

Caputo J (2009) Policy Paper: Sustainable Forest Biomass: Promoting Renewable Energy and Forest Stewardship; Environmental and Energy Study Institute.

Desrochers, L., Puttock, G.D., Ryans, M. (1994) The economics of chipping log residues at roadside. Biomass and Bioenergy 5 (6) Page 401-411

Greene, W.D; Westbrook M.D; Izlar R.L. Utilising forest biomass by adding a small chipper to a tree legth southern pine harvesting operation. Southern Journal of Apllied Forestry 2007; Volume 31 Number 14. Page 165-169.

Hall, P and Gifford, J (2008) Bioenergy Options for New Zealand. A Situation analysis of biomass resources and conversion technologies. Scion Energy Group, 2008. 83 pages.

Hamelinck, C.N, Faaij, A.P.C, Suurs, R.A.A. International bioenergy costs and energy balance In Biomass and Bioenergy 29 (2005) Page 114 – 134

Han, H., Johnson, L.R., Lee, H.W. (2004) Economic feasibility of an integrated harvesting system for small-diameter trees in southwest Idaho. Forest products Journal 54 (2) Page 21 – 27.

Hudson, J.B (1995) Integrated harvesting Systems. Biomass and Bioenergy, Volume 9, Nos 1-5. Page 141-151

International Energy Agency (2007) Good Practice Guidelines, Bioenergy project Development and Biomass Supply. IEA Publications, Paris, France 2007. 61 pages

Malinen, J., Pesonen, M., Maatta., Kajanus, Miika (2001) Potential harvest for wood fuels (energy wood) from logging residues and first thinnings in Southern Finland. Biomass and Bioenergy 20 (2001) Page 189-196

Ministry of Finance and National Planning (2009) 2010 Fiji National Budget in http://www.mfnp.gov.fj/Documents/2010_Budget_Address.pdf accessed 12 November 2009.

Patel, H (2009) Renewable Energy Development in Fiji – Fiji Electricity Authority in proceedings of the International Symposium of Renewable Energy, August 24 – 25 , 2009, University of the South Pacific, Suva, Fiji in http://www.usp.ac.fj/index.php?id=9161 accessed 28 October, 2009.

Puttock,G.D (1995) Estimating cost for integrated harvesting and related forest management activities In Biomass and Bioenergy 8 (2) Page 73-79. 1995

Richardson, J; Bjorheden,R; Hakkila,P; Lowe,A.T; Smith;C.T (2002) Bioenergy from Sustainable Forestry, Guiding principles and Practise. Forestry Sciences Volume 71. Kluwer Academic Publishers, The Netherlands 2002. 344 pages

Reserve Bank of Fiji (2009) September Quarterly Review in http://www.reservebank.gov.fj/docs/Quarterly%20Review%20(September%202009).pdf accessed 10 October 2009.

Sims, R.E.H (2005) Energy and Fuelwood Center of Energy Research, Massey University, Palmerston North, New Zealand In http://www.globalbioenergy.org/uploads/media/071105__Centre_of_Energy_Research__Massey_University__Sims__-_ENERGY_AND_FUELWOOD_01.pdf accessed 22 September, 2009.

Stuart, W.B., Porter, C.D., Walbridge, T.A., Orddrwald, R.G. (1981) Economics of modifying harvesting systems to recover energy wood. Journal of Forest Products 31 (8). Page 37-42

Visser, R., Spinnelli, R.,Stampfer,K (2009) Integrating biomass recovery operations into commercial timber harvesting: the New Zealand situation in http://www.bkc.co.nz/Portals/0/Reports/NZResiduePaperCOFE2009.pdf accessed 20 November 2009.

Evaluation of Bladed Skid Trail Closure and Cover BMPs for Erosion Control

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ABSTRACT

Sediment is one of the leading pollutants in our nation's water bodies. Within a silvicultural operation the majority of sediment originates from areas that are highly disturbed including areas such as decks, roads, and skid trails. Forestry Best Management Practices (BMPs) have been developed to minimize sediment export. BMP implementation is particularly important on skid trails because trails are built to lower standards and present the potential for increased erosion. Typical trail closure BMPs include installing water bars, and seeding with or without the application of mulch. The goal of our study was to determine the effectiveness of the following five closure and cover BMPs for bladed skid trails: 1) water bar only (Control); 2) water bar and grass seed (Seed); 3) water bar, grass seed, and mulch (Mulch); 4) water bar and piled hardwood slash (Hardwood Slash); and 5) water bar and piled pine slash (Pine Slash). To capture and quantify the amount of sediment being produced, geotextile devices known as dirtbags® were used. Bags were weighed after each major rainfall event or monthly, if no events occur, to assess the amount of erosion. In addition to field measurements, three soil erosion models were used to determine treatment effectiveness. The models used were the Universal Soil Loss Equation for Forestry (USLE), Water Erosion Prediction Project for Forest Roads (WEPP), and the Revised Universal Soil Loss Equation version 2 (RUSLE2). Preliminary results indicate significant treatment differences, with the Mulch, and Slash treatments being the most effective at reducing erosion.

INTRODUCTION

Sedimentation has clearly been identified as one of the most important sources of non point source (NPS) pollution in the United States (USEPA, 2003). Increased sedimentation can impair the natural functions of streams and rivers to a point where they become unsuitable for aquatic organisms (Virginia Department of Environmental Quality, 2007; Henley et al., 2000) and no longer can serve recreational needs (USEPA, 2003; Henley et al., 2000). Sedimentation derived from land uses such as agriculture, forestry, and urban development are the leading sources of NPS (USEPA, 2003; Yoho, 1980).

In response to the increased erosion potential from silvicultural operations, forestry Best Management Practices (BMPs) have been developed. Forestry BMPs mainly focus on highly disturbed areas within a silvicultural system that are most susceptible to erosion. These areas include roads, decks, and skid trails (Kochenderfer, 1977). BMPs are designed to reduce erosion by decreasing the amount and velocity of water thus decreasing its energy, and increasing the stability of the soil. BMPs used for roads, skid trails, and logging decks include: 1) proper planning, construction, and location; 2) control of grade; 3) control of water; 4) surfacing; and 5) road or trail closure (Grace, 2005; Swift and Burns, 1999; Swift, 1985). Bladed skid trail closure is important because skid trails are typically built to lower standards than haul roads and have the potential to produce more sediment. Typical closure BMPs include installing water control structures and applying cover. Water control structures such as water bars are used to divert water flow from the roadway and dissipate it over the adjacent forest floor. The spacing interval of water bars is dependent on the slope of the trail, as the slope increases the distance between bars decreases. Cover BMPs such as seeding, and seeding and mulching often reduce the amount of erosion by providing stability to the soil (Grace, 2002). The cover provided also decreases overland flow velocity and causes deposition of sediment before it reaches a waterway. Mulching provides immediate cover while the effects of seeding are not evident until the seed germinates. Piling slash on skid trails can also be a means of providing immediate cover and is recommended in southeastern states' BMP manuals (Georgia Forestry Commission, 2009; West Virginia Division of Forestry, 2009; North Carolina Division of Forest Resources, 2006; Virginia Department of Forestry, 2002); however there has been limited research into the effectiveness of slash as a soil stabilizer. One study conducted on volcanic soils in the western U.S. showed that piled slash reduced soil erosion by 99% when compared to bare mineral soil (McGreer, 1981).

To help land managers evaluate the effects of silvicultural activities on sedimentation, soil erosion models have been developed to predict erosion rates from both hillslopes and roads. Erosion prediction methods are also used to evaluate management practices and erosion control techniques (Elliot, 2004). Soil erosion models potentially provide a cost effective way to evaluate the performance of forestry BMPs. However, few erosion models have been calibrated for bladed skid trails.

The objectives of this study are to evaluate the performance of five closure and cover BMPs for the reduction of sediment production on bladed skid trails. The BMPs being evaluated are: 1) water bar only (Control); 2) applying grass seed (Seed); 3) applying grass seed with mulch (Mulch); 4) piling hardwood slash on trails (Hardwood Slash); and 5) piling pine slash on trails (Pine Slash). The treatment effectiveness is determined by both onsite field measurements and by use of soil erosion models. The soil erosion models being used are the Universal Soil Loss Equation for Forestry (USLE), the Water Erosion Prediction Project for Forest Roads (WEPP), and the Revised Universal Soil Loss Equation version 2 (RUSLE2).

METHODS

Study Site

The study site is located at Reynolds Homestead Research Center in the Piedmont physiographic region of Virginia. Reynolds Homestead is owned by Virginia Polytechnic Institute and State

University and is located in Patrick County. Patrick County is approximately 1,250 square kilometers and land is generally characterized by gently rolling terrain. The average temperature in January ranges from a high of 9°C to a low of -1.8°C. In July the average temperature ranges from a high of 29.7°C to a low of 17.8°C. The average precipitation is 151.9 cm with 125.2 cm being rainfall and the remaining 26.7 cm is snowfall (Patrick County, VA). The treatments are installed in a 5 hectare clearcut with side slopes of 15-20%. The dominant soil series on the site is Fairview sandy clay loam, fine, kaolinitic, mesic Typic Kanhapludults. This soil is formed from residuum from mica schist and mica gneiss and is very deep, well drained, and has an erodibility index of 0.28 (NRCS Soil Survey, 2009).

Experimental Design and Data Collection

Field Measurements

Treatments were installed on segments of bladed skid trail. There were a total of six bladed skid trails built with five treatments per trail. The study was designed as a Randomized Complete Block Design with the trails being designated as the six blocks and having a total of thirty experimental units.

Experimental units were approximately 15.2 meters (50 ft) in length by 3 meters (10 ft) in width and have water bars installed at the head and base of the treatment slope. Berms were maintained along the sides of each unit to ensure that no runoff produced from the treatment escapes and that no runoff from outside the unit area enters. Treatments were randomly assigned to each experimental unit.

- The Control treatment only has water bars installed. This treatment represents a commonly used closure BMP. Water bars were installed roughly at a 45 degree angle to the treatment slope. A high degree angle is preferable when installing water bars to ensure that as runoff reaches the water bar and is diverted into the adjacent off road area it will carry enough velocity to reach the outlet. Treatment water bars were built 0.6 to 0.9 meters (2 to 3 feet) in height to ensure that water will not overtop them, thus rendering them useless.

- Seed treatments consisted of water bars built at the head and base of the treatment and an application of seed. The seed mixture used was provided by Plum Creek Timber Company, Inc and consisted of winter rye (35%), timothy (10%), orchard grass (10%), perennial rye (10%), medium red clover (20%), and annual rye (15%). This mixture is used by Plum Creek Timber Company, Inc to close out skid trails on their company land in West Virginia. To promote germination, lime was applied at a rate of 2.25 Mg/ha (1 ton/acre), and a 10-10-10 fertilizer was applied at a rate of 227 kg/ha (200 lbs/acre). Seed was applied at a rate to ensure establishment (minimum 70% coverage) and was reapplied as necessary on treatments where germination was inadequate.

- Mulch treatments consisted of water bars built at the head and base of the treatment and an application of seed and straw mulch. The application of seed was the same as the Seed treatments and lime and fertilizer were applied at the same rates. Straw was applied after the application of seed at a rate that ensured 100% coverage. On a 15.2 meter (50 ft) by 3 meter (10 ft) slope length this equated to two straw bales.

- The Hardwood Slash treatments consisted of water bars and an application of hardwood slash. The hardwood slash was generated by felling small pole size trees in adjacent stands and cutting them into random lengths. The trees were harvested during March and April of 2009. The diameter of the felled trees ranged from 2.5 cm (1 in) to 15.2 cm (6 in) and the lengths ranged from 1.2 m (4 ft) to 3 m (10 ft). A combination of species were used and included white oak (*Quercus alba*), scarlet oak (*Quercus coccinea*), hickory (*Carya spp.*) yellow poplar (*Lirodendron tulipifera*), American beech (*Fagus grandifolia*), sourwood (*Oxydendrum arboreum*) and red maple (*Acer rubrum*). Slash was applied, using front end forks mounted on an agricultural tractor, initially to a waist high depth and then trampled down by a bull dozer to break up the slash and ensure good ground contact.

- The Pine Slash treatments consisted of water bars and an application of pine slash. The majority of the pine slash originated from a previous study conducted at Reynolds Homestead in February and March of 2009 and was composed of loblolly pine (*Pinus taeda*). The remaining pine slash was cut on the property in May of 2009 and consisted of Virginia pine (*Pinus virginiana*) and white pine (*Pinus strobus*). The lengths and diameters of the pine slash were similar to the hardwood slash and the application was the same as that of the hardwood slash.

Sediment produced from treatments was captured by gutters installed in trenches at the base of the treatments and then transported into a geotextile device, known as a dirtbag®, where the sediment was filtered (Figure 1).

Figure 1. Dirtbags® installed on bladed skid trail.

Dirtbags® are designed to filter sediment from construction site retention ponds but have been adapted for our use. Similar devices were utilized by Smith and Fenton (1992) to measure sediment from skid trails in New Zealand. To assess the amount of erosion that has occurred, dirtbag® weights were recorded monthly. Weights were measured by a Citizen HA crane scale, that has a weight capacity of 544 kg (1200 lbs), mounted on a metal arm attached to the blade of a John Deere 450E dozer. During measurements the moisture of the sediment within the bags was recorded using a time domain reflectometer (TDR). The bags were then classified into moisture classes, 1) saturated; 2) moist; and 3) dry, that described the moisture content of the bag itself. Correction factors were developed for each moisture class based on the surface area of the bag. The recorded weights were then adjusted by the sediment moisture and the moisture class correction factor.

Soil Models

The three soil erosion models used were the Universal Soil Loss Equation for Forestry (USLE), the Water Erosion Prediction Project for Forest Roads (WEPP), and the Revised Universal Soil Loss Equation version 2 (RUSLE2). Model predictions were analyzed, as a Randomized Complete Block Design, in the same manner as the field measurements. There were a total of 6 blocks with 5 treatments per block for a total of 30 experimental units.

Onsite measurements were taken at the onset of the study to describe the site conditions for use in the soil erosion models. The collected data was used to directly derive variables in the USLE and also to derive management files for use in RUSLE2 and WEPP. For model predictions, treatments were broken into two segments and erosion rates were calculated for each and then summed together for a total treatment erosion rate (Figure 2). The first segment includes the area from the top of the water bar at the head of the treatment to the base of the water bar at the foot of the treatment. The second segment is the area from the top of the water bar at the base of the treatment to the base of the same water bar. Treatments were divided in this manner because the slopes of the two segments are very different, with the water bar slope generally being in excess of 25%.

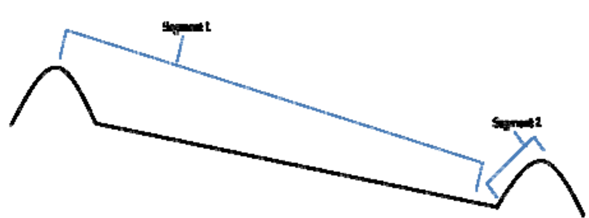

Figure 2. Treatment areas were separated into two segments and estimates were made for each segment and summed for a total erosion estimate

The equation that USLE uses to estimate erosion is as follows:

$$A = R*K*LS*CP$$

Where
A = amount of erosion per unit area per year
R = rainfall and runoff
K = soil erodibility factor
LS = slope length and steepness factor
CP = cover and management factor

An R value of 175 was used for all treatments and was taken from isoerodent maps found in the USLE handbook (Dissmeyer and Foster, 1984). A K value of 0.28 was used for all treatments and was found in the Patrick County Soil Survey (NRCS Soil Survey, 2009). The remaining factors were based on treatment specific conditions. For each treatment, LS values were determined based on slope profiles derived from elevation data collected by a total station, and CP values were based on data collected along four equidistant transects across each treatment area. USLE measurements were taken several times throughout the study. Multiple measurements were useful to examine the effects of season and time on erosion rates. We captured the effects that grass development and subsequent die back, slash decomposition, and soil reconsolidation had on erosion rates. USLE measurements were taken twice. A weighted average was used to develop estimates with the weights reflecting time between measurements. Also estimates were made pre and post grass establishment on Seed and Mulch treatments. We assumed that grass establishment took thirty days and appropriate weights were assigned to pre and post conditions.

RULSE2 originated from the empirically based USLE but has some process based functions and WEPP is a completely process based model. Both models are similar to one another in the data that is needed for model runs. Both require four types of information: 1) climate file; 2) soil file; 3) slope file; 4) and management file. Both models offer databases where climate files, soil files, and management files can be downloaded. These database files can be utilized or can be manipulated for site or treatment specific conditions. Both programs offer an interface for the user to input slope steepness and length values to create a slope file. In this analysis, climate and soils files were downloaded for Patrick County and management files were altered for treatments and are outlined in the following table (Table 1).

Table 1. Management file details for RUSLE2 and WEPP models

	Management Files	
Treatment	RUSLE2	WEPP
Control	Highly Disturbed Land/Blade Cut & Highly Disturbed Land/Track Walking Operation	Forest Bladed Road
Seed	Control File & Broadcast Seed Operation applying southern range grass	Control & annual ryegrass was planted at a medium fertilization rate
Mulch	Seed File & Highly Disturbed Land/Add Mulch Operation applying wheat straw: application rate based on coverage (≈100%)	Seed File & mulch residue addition of fescue at a rate of .788 kg/m^2 (≈2 straw bales per treatment)
Hardwood Slash	Control File & Highly Disturbed Land/Add Mulch Operation applying wood fiber. Response of wood fiber was changed to large woody debris and decomposition half life was increased to 1800 days (≈4.85 yrs). Application rate was based on percent coverage provided by treatments.	Control file & mulch residue addition of fesucue. The application rate was based on the amount of slash applied to treatments.
Pine Slash	Same as Hardwood except that the decomposition half life was further increased to 3600 days (≈19 yrs)	Same as Hardwood

RESULTS and DISCUSSION

Dirtbag® weights have been measured ten times since the onset of this study, for a total of 60 weights per treatment. Soil erosion model estimates have been developed for each experimental unit and there are a total of 6 estimates per treatment per model. Treatment averages are shown in Table 2 and ANOVA results are shown in Table 3. ANOVA results indicate that significant differences exist in both field measurement results and all three soil erosion model estimates.

Table 2. Mean erosion rates for treatments for Field Measurements and Soil Erosion Models

	Field Measurements		**USLE**		**RUSLE2**		**WEPP**	
Treatment	**tons/acre/yr**	**Mg/ha/yr**	**tons/acre/yr**	**Mg/ha/yr**	**tons/acre/yr**	**Mg/ha/yr**	**tons/acre/yr**	**Mg/ha/yr**
Control	67.5	151.9	48.6	109.4	96.0	216.0	14.7	33.1
Seed	18.0	40.5	32.8	73.9	10.2	23.0	9.5	21.3
Hardwood Slash	4.9	11.1	4.5	10.1	12.8	28.7	1.6	3.5
Pine Slash	3.5	7.8	1.8	4.1	10.6	23.9	1.8	4.1
Mulch	1.7	3.8	2.7	6.1	2.8	6.2	0.7	1.6

Table 3. Analysis of Variance results for treatments by evaluation method.

	F Value	Prob Level
Field Measurements	44.14	<.0001
USLE	28.75	<.0001
RUSLE2	303.13	<.0001
WEPP	286.97	<.0001

A tukey means separation test was used to determine treatment differences. Figure 3 shows the results from this test.

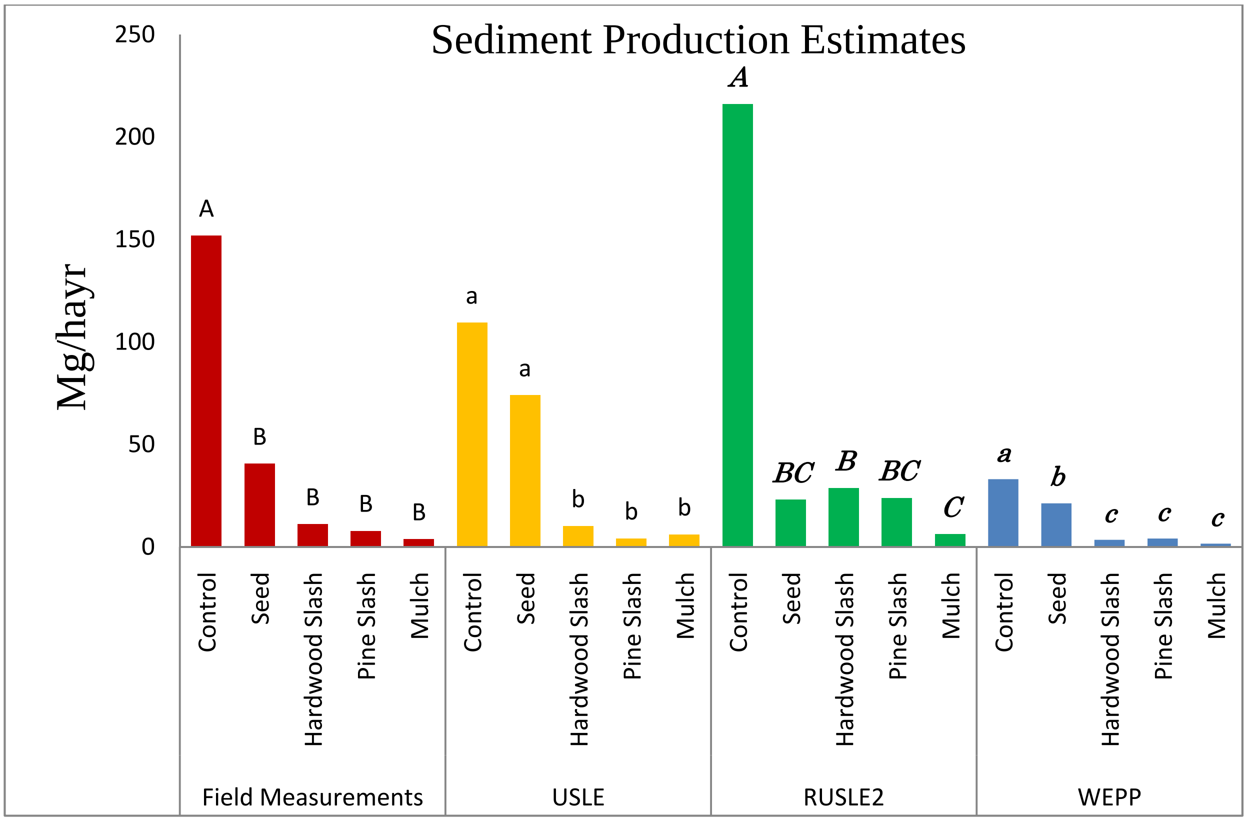

Figure 3. Treatment averages per evaluation method. Treatments with the same label are not significantly different

The results indicate that water bars alone are not always effective at preventing erosion and are not the best choice for trail closure in areas that are prone to erosion. Seed treatments offer some erosion control but are only slightly better than water bar alone. The amount of erosion control offered by seed applications depends on how much germination is achieved. In many cases applying seed alone achieves inadequate germination and very little erosion control is offered. The best erosion control was offered by the Hardwood Slash, Pine Slash, and Mulch treatments. In three of the four evaluation methods the Hardwood Slash, Pine Slash, and Mulch treatments differed very little. All methods except RUSLE2 showed the Slash and Mulch treatments to have erosion rates less than 10 Mg/ha/yr. When the small area of skid trails (generally < 10%) is weighted with the total harvest area, the sediment contribution becomes similar to agriculture.

CONCLUSION

In silvicutural operations it is very common to see trail closure consisting only of water bar installation and water bars are a commonly prescribed treatment in state BMP manuals (Virginia Department of Forestry, 2002). Water bars are certainly helpful and do offer erosion control. However, in areas where soil erosion is not tolerable, such as stream approaches, water bars alone should not be the only BMP implemented. In combination with water bars, BMPs that provide soil stability should be applied. Establishing grass on skid trails can be very effective at stabilizing the soil, but ensuring there is adequate germination can be difficult. Multiple applications of seed along with application of fertilizer and lime may be needed. Erosion control is also not immediate and only occurs after seed has germinated. Applying a mulching agent is the best way to prevent erosion from occurring. Slash and Mulch treatments were the most effective at erosion control because they provide the most ground cover, which serves to stabilize the soil by providing protection from rainfall impact and reduction in overland flow velocity. The protection offered by the Slash and Mulch treatments is immediate and therefore these treatments should be implemented in areas that are highly susceptible to erosion, such as steep grades and fill slopes.

In forest applications, slash in the form of tree tops and limbs is a readily available mulching agent. The protection provided by slash is very near to that provided by straw mulch. Slash also has a lower decomposition rate than does straw mulch and therefore has a longer residual lifespan. This study has covered a time span of ten months, but if these treatments were to be followed for a longer time period it is likely that we would see the erosion rates of Slash treatments leveling out with the erosion rates of the Mulch treatments. Eventually as the mulch decomposes, the erosion control provided by Slash treatments may surpass that of the Mulch treatments.

LITERATURE CITED

Dissmeyer, G. E., and G. R. Foster. 1984. A guide for predicting sheet and rill erosion on forestland. USDA For. Ser. Gen. Tech. Publ. R8-TP 6. 40p.

Elliot, W. J. 2004. WEPP internet interfaces for forest erosion prediction. Journal of the American Water Resources Association 40(2): 299-309.

Georgia Forestry Commission, 2009. Georgia’s best management practices for forestry. Georgia Forestry Commission, Macon. June 2009. 75p.

Grace, J. M., III. 2002. Control of sediment export from the forest road prism. Trans. ASAE 45(2): 1127 – 1132

Grace, J. M., III. 2005. Forest operations and water quality in the south. Trans. ASAE 48(2): 871-880.

Henley, W. F., M. A. Patterson, R. J. Neves, and A. D. Lemly. 2000. Effects of sedimentation and turbidity on lotic food webs: A concise review for natural resource managers. Reviews in Fisheries Science 8(2): 125-139.

McGreer, D. J. 1981. Skid trail erosion tests – First- year results. Potlatch Company Report.

North Carolina Division of Forest Resources, 2006. Forestry best management practices manual to protect water quality. North Carolina Division of Forest Resources, Raleigh. 243p.

NRCS Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/ accessed [May/13/2009].

Patrick County, Virginia. Climate. Available online at http://www.co.patrick.va.us/index.cfm?pg=13#climate. accessed [6/18/09].

Smith, M. and T. Fenton. 1992. Sediment yields from logging tracks in Kaingaroa Forest. Logging Industry Research Organization. Rotorua, NZ. 10 p.

Swift, L. W., Jr. 1985. Forest road design to minimize erosion in the Southern Appalachians. In: Blackmon, B. G., ed. Proceedings of forestry and water quality: a mid-south symposium. Monticello, AR: University of Arkansas. 141-151.

Swift, L. W., Jr. and R. G. Burns. 1999. The three Rs of roads. Journal of Forestry 97(8): 40-44.

USEPA. 2003. Nonpoint –source pollution: The nation's largest water quality problem. Washington, D.C.: U.S. Environmental Protection Agency, Office of Water, Nonpoint Source Control Branch. Available at: www.epa.gov/owow/nps/facts/point1.htm.

Virginia Department of Forestry. 2002. Virginia's best management practices for water quality. VA. Dep. For., Charlottesville. Fourth Edition July, 2002. 216p.

Virginia Department of Environmental Quality. 2007. Cleaning up impaired waters: TMDL progress report 2007. Virginia Department of Environmental Quality. 8p.

West Virginia Division of Forestry, 2009. West Virginia silvicultural best management practices for controlling soil erosion and sedimentation from logging operations. WV Division of Forestry, Charleston. 38p.

Yoho. N.S. 1981. Forest management and sediment production in the south – a review. Southern Journal of Applied Forestry 4(1): 27-36.

Kochenderfer, J. N. 1977. Area in skidroads, truck roads, and landings in the Central Appalachians. Journal of Forestry 75(8): 507-508.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

COMPARISON OF POTENTIAL EROSION FOLLOWING CONVENTIONAL AND CABLE YARDING TIMBER HARVESTS IN THE APPALACHIAN PLATEAU REGION OF VIRGINIA

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ABSTRACT – Cable yarding systems have potential environmental advantages over ground-based skidding on steep terrain. Our goal was to compare potential soil erosion losses from cable yarding and conventional skidder harvests in the steep Appalachian Plateau region of Virginia. We evaluated erosion on three sites where cable yarding and conventional skidding were occurring in close proximity by using the Universal Soil Loss Equation as adapted for forestlands (USLE-Forest) to model soil erosion. We estimated soil loss in a minimum of three locations for five yarder activities (deck, yarder landing, spur road, corridor, and harvest) and three skidder disturbance categories (deck, skid trail, and harvest). We used GPS to calculate the area in each disturbance category and used these values to estimate total overall erosion for the skidder and cable yarder harvests. Overall, the cable yarder and skidder operations produced similar potential erosion estimates of 1.86 and 1.70 tons/ac/yr, respectively. This similarity was caused primarily by the high estimated erosion (>25 tons/ac/yr) of the spur road that was used to connect the cable yarder landing with the log deck. On our sites, the current cable yarder operation did not offer clear erosion prevention advantages, but the yarding operation could have been significantly improved with greater attention to spur road layout and Best Management Practices (BMPs).

Introduction

Conventional harvesting systems on the steep terrain of the Appalachian Plateau region utilize ground-based skidders operating on skid trails bladed by bulldozers. Alternate harvesting systems for steep terrain, such as skyline cable yarding, are not as widely utilized or available in the region, but it is generally believed that such systems could be advantageous for minimizing area of disturbance as well as soil erosion (Miller and Sirois, 1986).

Best Management Practices (BMPs) for forest harvesting were developed to minimize erosion and protect water quality and subsequently help protect forest site productivity (Aust and Blinn, 2004). The region of operations, local soil types and weather conditions during the operation, and forest road and trail layout all influence soil erosion from timber harvesting operations.

Timber harvesting can cause significant changes in soil physical properties in the upper portion of the soil (Gent et al., 1984). When logs and litter are removed from a forest soil in timber harvesting and soil compaction occurs, the soil microbial biomass, soil moisture content, and nutrient levels are reduced (Jordan et al., 1999). Ground cover protects the soil in several ways, including energy dissipation of rainfall, wind, and surface runoff. Litter on the soil surface promotes infiltration, which decreases runoff (Clayton, 1981). The amount of damage to the soil surface and the litter layers varies for each logging operation; however, alternative harvesting systems such as cable yarding operations may potentially have less impact on the soil surface because the timber is partially lifted off the ground with a system of cables and towers. The ground-based systems create more disturbance of the surface soil and litter layer, which reduces overall soil quality.

Road construction and distribution over the forest floor is the major factor leading to potential erosion from harvesting systems. In skyline cable logging, the forest floor is primarily impacted in the cable corridors, where the logs are suspended above ground on the system of cables and towers. In these corridors, some soil disturbance will occur because some of the trees will be partially dragged on the ground, displacing the litter layer and exposing small areas of soil to erosion. In ground-based logging, skid roads are constructed across the entire harvest area to pull the trees to a landing and loading area. The ground-based system has the greatest impact on the surface soil and litter layer because heavy equipment is operating on the soil surface.

Ground-based timber harvesting operations have the potential to cause severe soil disturbances that can reduce soil productivity, particularly when ground-based operations require construction of bladed skid trails (Aust et al., 2006). In addition to removal of the litter layer and compaction, bladed skid trails sidecast the surface soil and create low standard roads that can amount to 10% of the area (Kochenderfer et al., 1997). These skid trails typically have reduced site productivity and increased the drainage density of the site, thus contributing additional sediment to streams (Eisenbies et al., 2007).

Ground-based logging usually produces well-defined skid trails on the forest floor. Soil compaction negatively impacts soil structure and is less favorable to tree growth. The impact of skid trail construction on the growth of the next forest crop is dependent upon the number and distribution of skid trails over the harvest site. One way to reduce the impacts on soil quality would be to carefully locate and mark all skid trails to be used during the ground-based harvesting operation (Froehlich, 1957). The impact of conventional logging systems rests in the number and distribution of the skid roads, so it is very important for forest managers to limit the number of skid roads that the logging operation uses on the forest site.

Alternative harvesting systems can effectively remove timber from the forest and help maintain soil quality by having less impact on the entire harvest site. For example, skyline cable logging caused substantially less site disturbance than rubber-tired cable skidders in research studies in the mountains of Georgia (McMinn, 1984).

Soil erosion becomes sediment when it enters a stream. Much of the eroded soil will be trapped in the litter on the forest floor before reaching a stream. Yoho (1980) reported that undisturbed mixed forests produced up to 0.32 tons/ac/yr year of sediment movement offsite. He also reported from 0.06 to 0.17 tons/ac/yr of sediment yield in a carefully clearcut forest, while a carelessly harvested clearcut generated 1.35 tons/ac/yr of sediment. Sediment production from a timber harvest is increased when stream banks and channels are disturbed by logging equipment (Yoho, 1980). Cable logging systems suspend or partially suspend the logs off the ground in the skidding process, almost eliminating the possibility of disturbance to stream banks or channels. However, conventional logging systems that use ground-based skidders must sometimes cross streams in order to reach all areas of the harvest, and any type of stream crossing will cause some impact to the stream banks and potentially to the stream channel. Kochenderfer et al. (1997) found that sediment doubled during the first year after harvest but returned to pretreatment levels within three years. Swank et al. (2001) found large increases in sediment following road construction and major storm events. Sediment from logging activities was greatly reduced and insignificant when the logging was completed (Swank et al., 2001).

Timber harvesting can increase erosion, sediment, and nutrient losses to streams. Aust and Blinn (2004) found the sediment quantities introduced to streams to be relatively low and below the levels that are considered acceptable for alternative land uses. Most studies indicate that within five years of a timber harvest, the water quality recovers, especially when BMPs are followed in the harvesting operations (Aust and Blinn, 2004). Croke et al. (2001) found that erosion rates declined by almost one order of magnitude over a five-year period following harvesting.

Our research objective was to compare erosion rates on sites harvested with cable yarders with erosion rates on similar sites harvested with tracked cable skidders.

Methods

The research was conducted on private forestland in Dickenson County, Virginia. The study sites were located in the Appalachian Plateau physiographic province, a region characterized by steep relief. The soil series in the study areas were dominated by the Highsplint-Shelocta and the Matewan-Gilpen soils. These soils are loams to sandy loams and side slopes ranged to above 100%. The study sites contained a variety of cove and upland hardwood species, including northern red oak, chestnut oak, white oak, yellow-poplar, and red maple.

The harvesting systems were a cable yarder with a 30-foot tower and maximum corridor reach of 1200 feet. A bulldozer was used to pull the logs from the yarder to a knuckleboom loader for processing into logs and pulpwood. The mechanical logging was completed with a tracked cable skidder (bulldozer). The terrain on the sites required bulldozer logging to be completed with bladed skid trails across the harvest area. Both harvesting systems used manual tree felling.

Potential soil erosion was estimated using the Universal Soil Loss Equation as modified for forest land by Dissmeyer and Foster (1984). Data were collected on the harvest sites in the summer of 2009, six to nine months after the harvest was completed. The soil erodibility factor was determined from the USDA NRCS Soil Survey for Dickenson County. Slopes were measured with a Suunto clinometer. Distances were determined with a GPS receiver. The area was calculated from timber sale maps by using the recorded distances and measurements.

The study was analyzed as a randomized complete block design having three blocks of two treatments. The two treatments were conventional logging and yarder logging. Soil disturbance was classified into categories for each harvesting system. The locations sampled on the conventional harvest sites were the deck, the bladed skid trails, and the harvest area. The locations sampled on the yarder logging sites were the harvest area, the yarder site, the yarder road used to pull logs from the yarder to the landing, and the corridor. For each location, one sample was collected on the deck; three samples in the harvest area; six samples on skid trails; three samples on yarder roads; six samples in corridors; one sample on each yarder site; and one sample in an unharvested area adjacent to the site. All the harvest sites were regeneration harvests.

Results and Discussion

The timber harvesting operation used both cable yarding and tracked skidding to complete the entire timber harvest. The components of the harvesting system are shown in Figure 1. The cable yarding side of operations included a deck used for processing and loading; a spur (bladed) road used to pull the logs from the yarder landing to the deck; the yarder landing; and the corridors across the harvest area where the mainline was used to pull the logs to the yarder landing. The tracked skidder operation used the same deck and consisted of a system of bladed skid trails used by the bulldozer to pull logs to the deck.

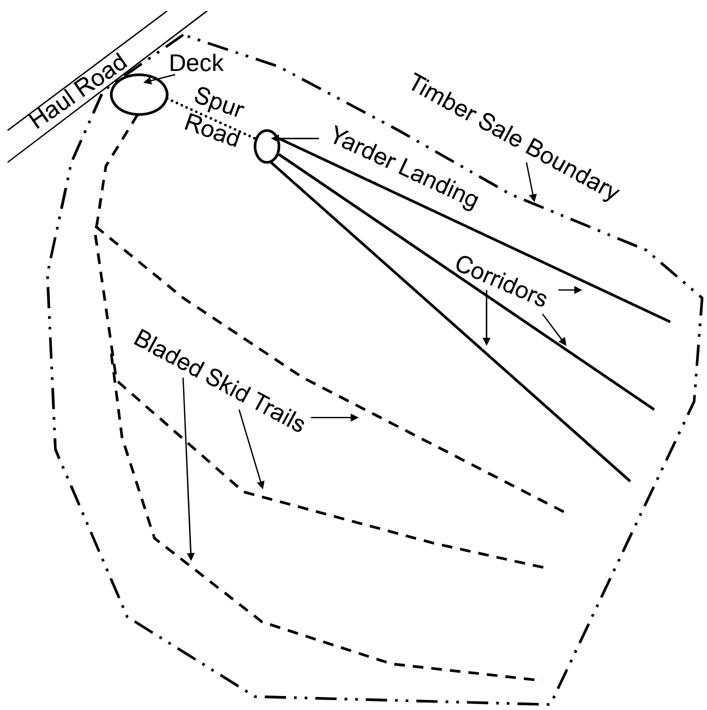

Figure 1. Components of the timber harvesting operation.

The harvested areas had an average erosion rate of 0.6 tons/ac/yr, while nearby unharvested areas had an average erosion rate of 0.47 tons/ac/yr (Table 1). Conventional logging with a tracked cable skidder had 1.86 tons/ac/yr average erosion rate from the three research sites. The greatest soil erosion rate found on the tracked skidder operation was from the bladed skid trails, at 17.18 tons/ac/yr.

The tracts harvested with the cable yarder system had an average erosion rate of 1.7 tons/ac/yr. The spur roads had the highest erosion rate, 25.06 tons/ac/yr. The area of the spur roads averaged

0.17 acres per site; however, they generated 34% of the sediment from the cable yarding operation.

The logs were pulled to the deck by either the tracked skidder or the cable yarder. The main difference between the cable logging system and the mechanical logging system was the method of in-woods transport of the trees. The cable system utilized the cable yarder and pulled the logs to the landing through the corridors. The cable skidder used bladed skid trails to pull logs to the deck. The study showed that the spur road and skid trails had the greatest erosion rates. The skid trails had an average erosion rate of 17.18 tons/ac/yr, while the spur roads had an average erosion rate of 25.06 tons/ac/yr. The three sites had an average of 0.97 acres of skid trails and 0.17 acres of spur roads. There was an average of 1.22 acres of corridors with an average erosion rate of 4.49 tons/ac/yr, which generated 5.14 tons of soil loss.

Table 1. Average predicted soil loss for three Appalachian sites harvested with tracked cable skidders on bladed skid trails and cable yarder systems by disturbance categories.

Harvest System	Disturbance Category	Average Erosion Rate (tons/ac/yr)	Average Area (ac)	Average Total Erosion (tons/yr)
None	Nonharvested	0.47	---	---
Tracked cable skidder	Deck	1.16	0.11	0.13
	Skid trail	17.18	0.97	16.68
	Harvest	0.6	11.92	6.75
	Overall	1.86	12.67	23.56
Cable yarder	Deck	1.16	0.11	0.13
	Yarder landing	1.05	0.057	0.06
	Spur road	25.06	0.17	4.21
	Corridor	4.49	1.22	5.14
	Harvest	0.6	5.78	2.92
	Overall	1.7	7.33	12.46

In getting the logs from the stump to the deck, the cable system yielded a lower rate of soil erosion than did the skid trails. The low erosion rate in the corridors shows the benefit of cable logging operations. The skid trails generated an erosion rate of 17.18 tons/ac/yr, while the corridors only yielded 4.49 tons/ac/yr of soil loss. To reduce the amount of soil erosion from timber harvesting operations, cable yarding systems should be utilized. The cable system allows the skidding of logs and pulpwood without having to build bladed skid trails on steep mountain slopes. However, to reduce overall soil erosion from cable logging systems, the high erosion rate of the spur roads must be decreased.

With improved preharvest planning, the number of spur roads could be reduced, which would decrease the total erosion from the harvesting site. The spur roads had the greatest erosion rates on average, yielding 25.06 tons/ac/yr of sediment. This erosion rate is high; however, on average, the three yarding sites had 0.17 acres of this disturbance area.

With regard to the total average soil loss from these harvesting systems, the cable yarding system yielded 11.1 tons/yr less than the tracked cable skidder system. The tracked skidder sites in the study involved more acreage, but when the total erosion from the skid trails (16.68 tons/yr) is compared with the total erosion from the yarder landing, spur road, and corridors (9.41 tons/yr), it can be seen that the tracked cable skidder system produced 7.27 tons/yr more erosion than the cable yarding system.

A more complete pre-harvest plan could reduce erosion from cable yarding operations. The key would be to locate the yarder landing close to the deck so the need for spur roads can be reduced. If spur roads are needed, then better layout using BMPs could reduce the erosion rate from this disturbance area. Reducing the number and acreage of spur roads would reduce the amount of erosion from the harvest site, because the spur roads were found to have the highest erosion rate in the study.

The data from all three research sites are compared in Table 2. On Site 1, the cable yarder system and the skidder operation had the same average erosion rates of 1.03 tons/ac/yr. The average erosion rate for the spur roads was 30.25 tons/ac/yr, while the average erosion rate for the skid trails was only 15.64 tons/ac/yr. The data for Site 2 show that the average erosion rate for the cable yarder system was 2.31 tons/ac/yr, while the skidder operation had an average erosion rate of 1.43 tons/ac/yr. This illustrates the importance of improving pre-harvest planning to improve the layout and use BMPs for spur roads in a cable logging operation. In Site 2, the erosion rate for the spur road was more than double the erosion rate for the skid trails, at 24.91 and 9.96 tons/ac/yr, respectively. The data from Site 3 show that the skid trails had a higher erosion rate (25.95 tons/ac/yr) than the spur roads, which had a rate of 20.02 tons/ac/yr.

Summary

Forest harvesting operations can potentially have tremendous impacts on soil quality. Our study found that a conventional logging system with a tracked cable skidder created more erosion on harvesting sites than a cable yarder system. However, only a small decrease in erosion was found with the cable logging system. The largest erosion rate from all the disturbance categories in the study was found on the spur roads, with an average of 25.06 tons/ac/yr of soil loss. More advanced rigging techniques could possibly enhance the effectiveness of the yarder equipment, which could reduce the need for spur roads by having the yarder landing beside the log deck. Better pre-harvest planning in cable logging operations could improve the layout of the deck, the yarder landing, and the spur roads. If the spur road disturbance was reduced or eliminated from the operation, there could be significant reductions in erosion from cable logging operations.

Table 2. Predicted soil loss for three Appalachian sites harvested with tracked cable skidders on bladed skid trails and cable yarder systems by disturbance categories.

	Skidder Operations				Yarder Operations			
Site	Disturbance Category	Area (ac)	Average Erosion (tons/ac/yr)	Estimated Total Erosion (tons/yr)	Disturbance Category	Area (ac)	Average Erosion (tons/ac/yr)	Estimated Total Erosion (tons/yr)
1	Deck	0.1	1.48	0.15	Deck	0.1	1.48	0.15
	Skid trail	0.63	15.64	9.85	Yarder landing	0.08	0.94	0.08
	Harvest	12.27	0.28	3.43	Spur road	0.14	30.25	4.24
					Corridor	1.57	2.76	4.34
					Harvest	9.11	0.28	2.55
	Total	13.0	1.03	13.43	Total	11.0	1.03	11.36
2	Deck	0.12	1.04	0.13	Deck	0.12	1.04	0.13
	Skid trail	1.17	9.96	11.65	Yarder landing	0.05	1.01	0.05
	Harvest	12.71	0.65	8.26	Spur road	0.19	24.91	4.73
					Corridor	1.24	4.89	6.06
					Harvest	4.4	0.65	2.86
	Total	14.0	1.43	20.04	Total	6.0	2.31	13.83
3	Deck	0.1	0.96	0.1	Deck	0.1	0.96	0.1
	Skid trail	1.1	25.95	28.55	Yarder landing	0.04	1.19	0.05
	Harvest	9.8	0.87	8.57	Spur road	0.18	20.02	3.67
					Corridor	0.86	5.83	5.02
					Harvest	3.82	0.87	3.34
	Total	11.0	3.38	37.22	Total	5.0	2.44	12.18

References

Aust, W. M., and C.R. Blinn. 2004. Forestry best management practices for timber harvesting and site preparation in the eastern United States: An overview of water quality and productivity research during the past 20 years (1982–2002). Journal of Water, Air & Soil Pollution: Focus 4(1):5-36.

Aust, W.M., T.C. Fristoe, P.A. Gellerstedt, L.A.B. Giese, and M. Miwa. 2006. Long-term effects of helicopter and ground-based skidding on site properties and stand growth in a tupelo-cypress wetland. Forest Ecology and Management 226:72-79.

Clayton, J.L. 1981. Soil disturbance caused by clearcutting and helicopter yarding in the Idaho Batholith. USDA Forest Service. Intermountain Forest and Range Experiment Station. Research Note INT-305. 7 pp.

Croke, J., P. Hairsine, and P. Fogarty. 2001. Soil recovery from track construction and harvesting changes in surface infiltration, erosion and delivery rates with time. Forest Ecology and Management 143(1-3):3-12.

Dissmeyer, G.E., and Foster, G.R. 1984. A guide for predicting sheet and rill erosion on forest land. USDA Forest Service, State and Private Forestry Technical Publication R8-TP-6. 40pp.

Eisenbies, M.H., W.M. Aust, J.A. Burger, and M.B. Adams. 2007. Forest operations, extreme flooding events, and considerations for hydrologic modeling in the Appalachians—A review. Forest Ecology and Management 242(2-3):77-98.

Froehlich, H.A. 1957. Designing skid trail systems to reduce soil impacts from entractive logging machines. Forest Research Laboratory, School of Forestry, Oregon State University, Research Paper 44. http://hdl.handle.net/1957/8240

Gent, J.A. Jr., R. Ballard, A.E. Hassan, and D.K. Cassel. 1984. Impact of harvesting and site preparation on physical properties of Piedmont forest soils. Soil Science Society of America Journal 48:173-177.

Jordan, D., F. Li, F. Ponder, Jr., E.C. Berry, V.C. Hubbard, and K.Y. Kim. 1999. The effects of forest practices on earthworm populations and soil microbial biomass in a hardwood forest in Missouri. Applied Soil Ecology 13(1):31-38.

Kochenderfer, J.N., P.J. Edwards, and F. Wood. 1997. Hydrologic impacts of logging an Appalachian watershed using West Virginia's best management practices. Northern Journal of Applied Forestry 14(4):207-218.

McMinn, J.W. 1984. Soil disturbance in mountain hardwood stands. Georgia Forest Research Paper 54. Georgia Forestry Commission, Macon. 7 pp.

Miller, J.H., and D.L. Sirois. 1986. Soil disturbance by skyline yarding vs. skidding in a loamy hill forest. Soil Science Society of America Journal 50:1579-1583.

Swank, W.T., J.M. Vose, and K.J. Elliott. 2001. Long-term hydrologic and water quality responses following commercial clearcutting of mixed hardwoods on a southern Appalachian catchment. Forest Ecology and Management 143:163-178.

Yoho, N. S. 1980. Forest management and sediment production in the South – A review. Southern Journal of Applied Forestry 4(1):27-36.

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

VALIDATION OF A NEW CONCEPTUAL CABLE HARVESTING SYSTEM USING AN INDEPENDENT DEVICE FOR LATERAL YARDING

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Abstract: Forest harvesting on the ground with a harvester or harwarder made a significant stride in the productivity while cable harvesting systems used on steep slopes have not greatly improved since the combined yarder/processor was developed. In this study, we proposed a cable harvesting system using an independent device for lateral yarding, which was expected to improve the productivity of the cable harvesting system with less intensive investment. Then, we estimated the productivity of the system when the independent device for lateral yarding was introduced to the conventional gravity system. As a result, the productivity of the new cable harvesting system was better than that of the conventional gravity system for all distances (20-300m). It was also found that the effect of the independent device for lateral yarding was limited for the yarding distances of 20-80m because the carriage must wait for logs to be loaded at the loading point. On the other hand, the total yarding time of the conventional gravity system increased in proportion to the yarding distance. In conclusion, the new cable harvesting system had the advantage in the productivity over the conventional gravity system when the yarding distance was 140m or more.

Key words: cable harvesting system, computer simulation, independent device for lateral yarding, system dynamics

Introduction

Modern technology in forest harvesting on the ground such as a harvester or harwarder achieved the higher productivity than ever before. On the other hand, cable harvesting systems used on steep slopes have not greatly improved since the combined yarder/processor was developed. Harvesting costs on steep slopes especially for thinning or collecting small trees must be reduced by introducing innovative techniques to cable harvesting systems. In the previous study (Yoshimura and Hartsough 2007a), we proposed new concepts of cable systems that could improve the productivity of harvesting forest biomass: gondola cable system, draw-well system, double-track system and double-carriage system. This study was done based on the belief that developing such innovative techniques required revolution rather than incremental improvements to existing cable systems. However, these new concepts have not yet been brought to realization because intensive investment is necessary for the development of basic technology and production of test models of the systems. There is a similar cable harvesting system that has been experimentally developed and examined by Tasaka et al. (2006) and Aruga et al. (2009). This system uses two carriages, and they are combined in the middle of the cable to transmit the load from one to another carriage. Thus, the total time for carriage travel can be reduced. However, two carriages must slow down before they are combined, and this means this system is suited to the middle- or long-span yarding. Moreover, there may be a mismatch between loading and unloading time, and waiting time of carriage cannot be entirely eliminated. To cut down these problems, we proposed a cable harvesting system using an independent device for lateral yarding, which was expected to improve the productivity of the system with less intensive investment.

In this study, we also estimated the productivity of cable harvesting systems by using computer simulation. System dynamics simulation was employed to make a flexible and customizable model to better fit the actual conditions as we did in the previous studies (Yoshimura and Hartsough 2007a and Yoshimura and Hartsough 2007b). McDonagh et al. (2004) applied system dynamics simulation to select an appropriate harvesting system for a given stand by comparing the productivity of several harvesting systems: manual fell/cable skid, mechanized fell/grapple skid, shovel bunching/grapple skid and cut-to-length harvesting/forwarding. Nitami (2005) showed the possibility of making a model of forest operations based on the transition probability by using system dynamics. Nitami (2006) applied system dynamics simulation to estimate the productivity of a harvesting system that included forest road construction, felling by chainsaw, extraction to forwarder trails by grapple-equipped excavator, bucking and delimbing by chainsaw, log collection by forwarder and log piling. Sugimoto et al. (2010) compared the operation time, cost and productivity between a flow harvesting system and a disjointed system by using system dynamics models. The current analysis used system dynamics simulation to predict the productivity when the independent device for lateral yarding is introduced to the conventional gravity system, and we considered the advantages and disadvantages of this system prior to actual development of equipment.

Materials and methods

It is known that lateral yarding lowers the productivity of cable harvesting systems. In fact, line thinning is very popular in Japan because it eliminates time for lateral yarding when logs are transported by using a mobile yarder. Therefore, we proposed a new cable harvesting system using an independent device, which is attached to the skyline and works exclusively for lateral yarding (Figure 1.). By using this device, we can transport logs on the skyline while lateral yarding is going on at the same time. When the carriage arrives at the point of loading, lateral yarding has already been completed. This, it is expected that this system improves the productivity of cable harvesting systems. Figure 2 shows the combination of the independent device for lateral yarding and carriage, which can work separately. The independent device has an engine or motor to pull logs up to the skyline. When lateral yarding of logs has been completed, these logs are transferred to the carriage automatically (Figure 3). Log transfer system needs to be developed to realize automatic log transfer between the independent device and carriage. After logs have been transferred to the carriage, it starts to move up to the unloading point or landing. While the carriage moves up and down, lateral yarding is carried out with the independent device. When all logs have been harvested at the loading point, the independent device can be relocated to the next loading point by connecting it to the carriage and moving it with the power of the carriage (Figure 4). All such operations can be done by using the remote control system.

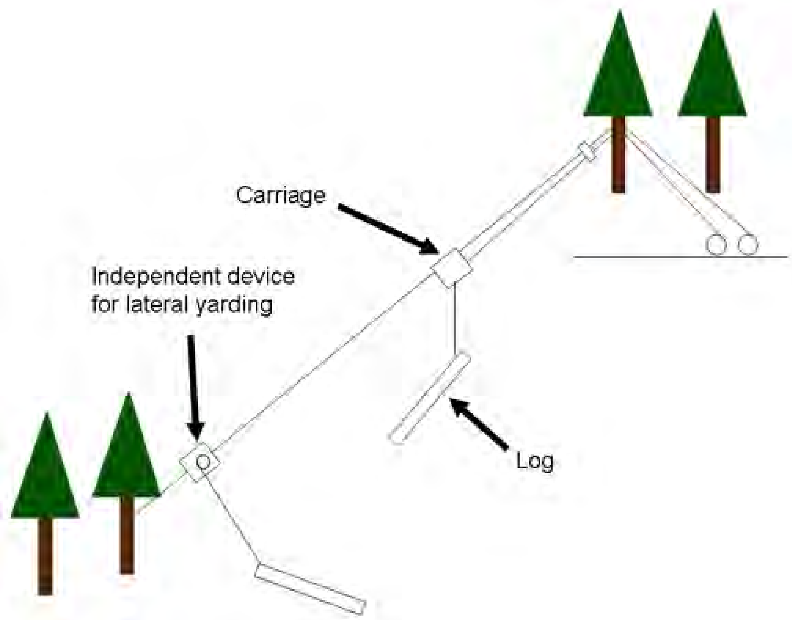

Figure 1. Concept of a new cable harvesting system using an independent device for lateral yarding.

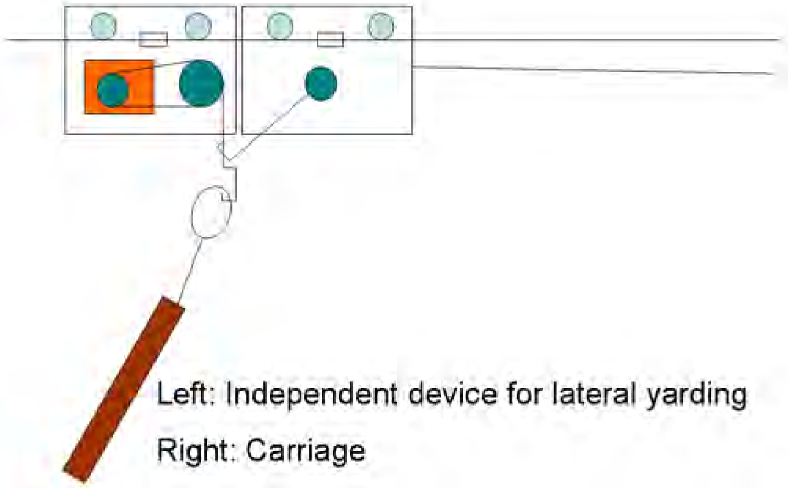

Figure 2. Combination of the independent device for lateral yarding and carriage.

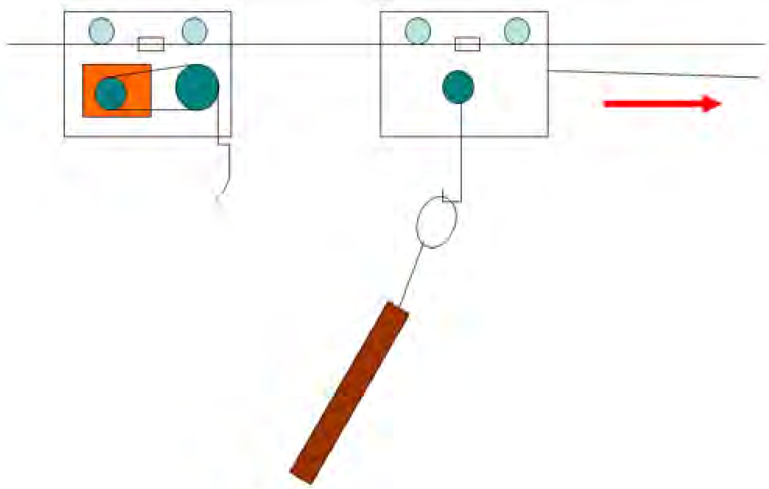

Figure 3. Log transfer system between the independent device and carriage.

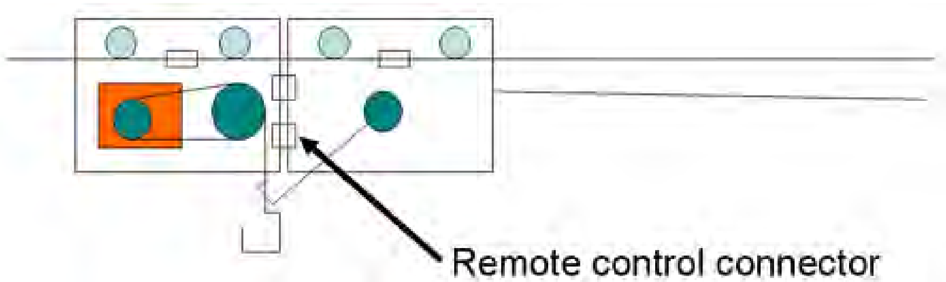

Figure 4. Relocation of the independent device using the remote control connector.

We evaluated the new cable harvesting system in terms of productivity by using system dynamics simulation, which helps us understand the behavior of complex systems over time. System dynamics also has the advantages of high compatibility, interchangeability, understandability and simplicity of models. It is also characterized by its methodology for modeling complex feedback systems, which mean a closed system influenced by its past behavior. For modeling the new cable harvesting system, we used STELLA 9.1.3 (ieee systems), a visual diagram-based simulation application program for system dynamics models. Figure 5 shows the four crucial components used in STELLA: stock, flow, converter and connector. The definitions of these components are explained as follows:

Stock: Memory that accumulates or drains materials over time.
Flow: Movement of materials from one stock to another.
Converter: Auxiliary variables to give values from constants, algebra or graphs.
Connector: Information carrier from one element in a model to another element.

In addition, we used two more components derived from the stock for modeling cable harvesting systems (Figure 5):

Conveyor: A derivative type of stock, into which materials flow and in which materials stay for a fixed amount of time, then exit.
Oven: A derivative type of stock that acts like an oven. When the limit of the oven is reached, the oven closes and holds the inflow for a certain time. Then, the oven lets the contents out through the outflow.

We made a system dynamics simulation model of the new cable harvesting system as well as the conventional gravity-return system with, as an example, a Koller yarder and carriage. It is assumed that total volume of harvested logs is 100m^3 and yarding distance is 20-300m. The uphill (travel loaded) and downhill (travel empty) carriage speeds are set to 1m/s and 8m/s, respectively. The weight of load or logs is 2m^3. In this model, time for lateral yarding increases from 100 to 200sec as harvesting process goes on to reflect the increase of lateral yarding distance. Time to transfer the load from one to another carriage is set to 10sec, and unloading time is set to 30sec. To simplify the models, we did not consider empirical time relationships or stochastic time distributions. We do not believe that it is necessary to incorporate time distributions into the models because the goal of this study is conceptual evaluation in terms of productivity. Figures 6 and 7 show the models of the conventional gravity system and the new cable harvesting system, respectively.

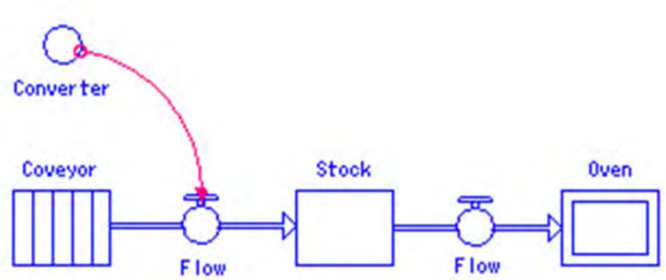

Figure 5. Four crucial components and two additional components derivative from the Stock.

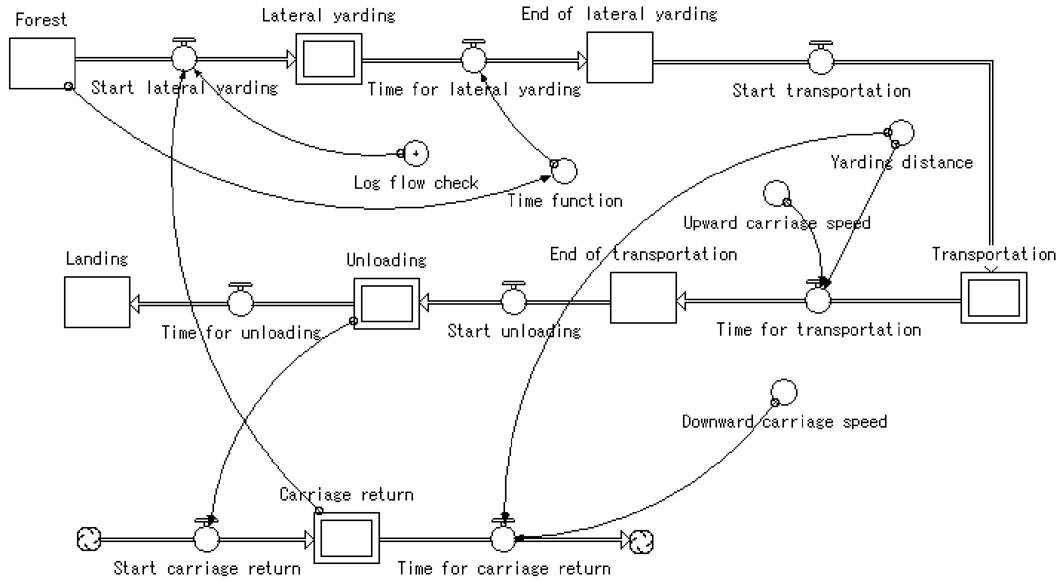

Figure 6. Simulation model of the conventional gravity system.

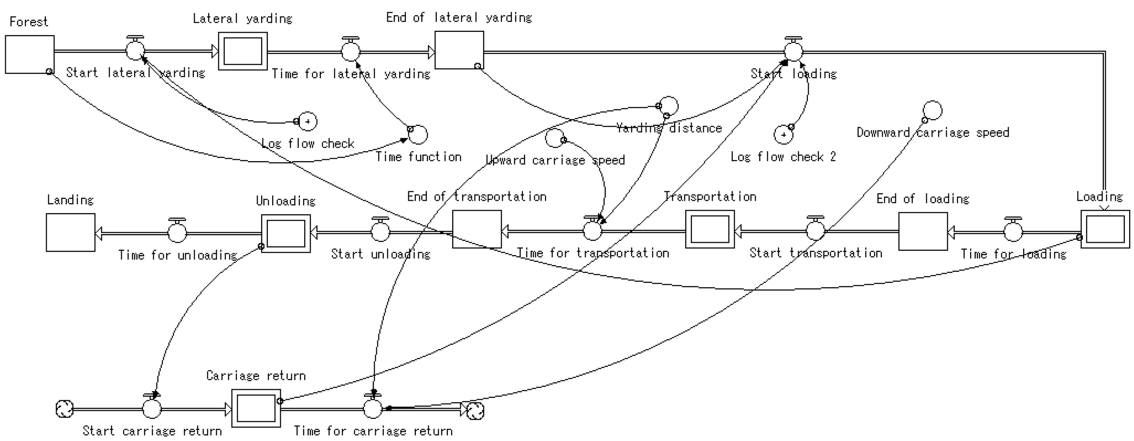

Figure 7. Simulation model of the new cable harvesting system using an independent device for lateral yarding.

Results and discussion

Figure 8 shows the comparison of the productivity of the conventional gravity system vs. new cable harvesting system. In this figure, the yarding distance varies from 20 to 300m. As shown in this figure, the productivity of the new cable harvesting system was better than that of the conventional gravity system for all yarding distances. It was also found that the total yarding time of the new cable harvesting system did not vary much when the yadring distance was 20-80m. This indicates the effect of the independent device for lateral yarding was limited for such distances because the carriage must wait for logs to be loaded at the loading point when the yarding distance was relatively short. On the other hand, the total yarding time of the conventional gravity system increased in proportion to the yarding distance. This figure also shows that the yarding time can be saved for around 6800sec by using the new cable harvesting system when the yarding distance was more than 140m. The yarding time rate of the new cable harvesting system to the conventional gravity system was minimum (58.1%) when the yarding distance was 120m, and it was maximum when the yarding distance was 20m (79.5%). In conclusion, the new cable harvesting system has the advantage in the productivity over the conventional gravity system when the yarding distance was 140m or more. However, it also depends on the conditions other than the yarding distance. We can calculate the optimum yarding distance on the various conditions by using the system dynamics model we proposed in this study. We will further explore the new concept of the cable harvesting system in future studies.

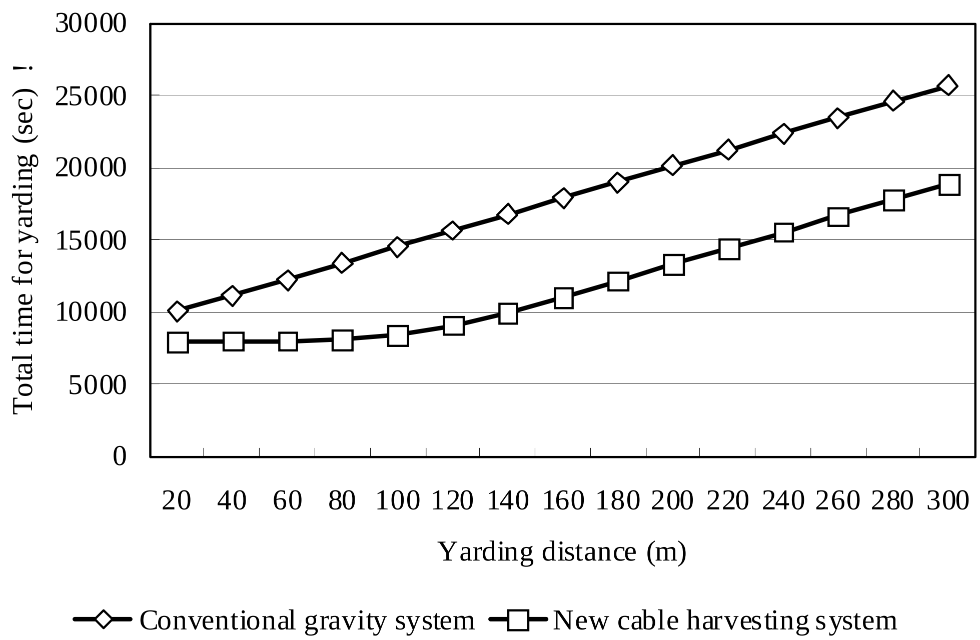

Figure 8. Comparison of the productivity of the conventional gravity system vs. new cable harvesting system.

Literature cited

Aruga, K., Tasaka, T., Nishikawa, A., and Yamasaki, T. 2009. Development of a new operation system with carriages for turn back yarding system. Proceedings, Environmentally Sound Forest Operations 32nd Annual Meeting of the Council on Forest Engineering: CD-ROM, 2009

McDonagh, K.D., R.D. Meller, R.J.M. Visser and T.P. McDonald. 2004. Harvesting System Simulation Using a Systems Dynamic Model. Southern Journal of Applied Forestry 28(2):91-99.

Nitami, T. 2005. System dynamics representation for forest operations and the application – utilizing transition probability of element work –. Journal of Forest Engineering 19(4):271-273. (in Japanese)

Nitami, T. 2006. Modeling of timber harvesting operation by system dynamics and the productivity estimation function. Journal of Forest Engineering 20(4):281-284. (in Japanese)

Sugimoto, K., Niinaga, S., and Hasegawa, H. 2010. Consideration on flow harvesting system utilizing system dynamics. Journal of Forest Engineering 25(1):5-14. (in Japanese with English summary)

System dynamics in education project. Road maps glossary. Accessed April 25, 2010 at http://sysdyn.clexchange.org/sdep/Roadmaps/RMGlossary/D-4498.pdf

Tasaka, S., Aruga, K., and Kojima, T. 2006. Development of a new carriage for turn back yarding system. Journal of Forest Engineering 20(4):225-228. (in Japanese)

Yoshimura, T. and Hartsough, B. 2007a. Conceptual evaluation of harvesting systems for fuel reduction and biomass collection on steep terrain using system dynamics. Proceedings of the International Mountain Logging and 13th Pacific Northwest Skyline Symposium: 94-102.

Yoshimura, T. and Hartsough, B. 2007b. Conceptual evaluation of ground-based harvesting systems for fuel reduction and biomass collection using system dynamics. 3rd Forest Engineering Conference: CD-ROM

COFE. 2010. In: Proceedings of the 33rd Annual Meeting of the Council on Forest Engineering: Fueling the Future. Compiled by D. Mitchell and T. Gallagher. [CD]

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