FOREST BIOMASS RECOVERY BY ADDING SMALL CHIPPERS TO TREE-LENGTH HARVESTING SYSTEMS IN PLANTED PINE STANDS OF THE SOUTHERN USA

by

MICHAEL D. WESTBROOK, JR.

(Under the Direction of W. Dale Greene)

ABSTRACT

We investigated the addition of a small chipper (Conehead 565 or Woodsman 334) to mechanized, tree-length systems in planted southern pine stands to harvest tops, limbs, and understory (dbh 1-4 inch) biomass in addition to traditional roundwood products. The systems were examined in three replicated studies involving clearcuts and thinnings in 2006 - 2007 in Georgia. Understory standing biomass (excluding the limbs and tops of merchantable stems) ranged from 3.7 to 26.3 tons per acre in the three studies. Chipping the limbs and tops of merchantable stems did not reduce the production of roundwood, but only produced 3-4 tons per acre of biomass. Harvesting understory biomass in addition to chipping limbs and tops worked well with clearcut harvests, but reduced roundwood production by 50% in the thinning study. Small chippers added to roundwood operations appear to have the most potential in clearcut harvests where less than 15 tons per acre of biomass are harvested and daily chip production is approximately 70-80 tons per day (2-3 truckloads). Green chips averaged 45% moisture content while dry chips had higher heating values of 8200 BTU/lb, which is comparable to other woody biomass.

INDEX WORDS: Forest Biomass, Logging, Harvesting, Fuel Chips, Chipping

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The University of Georgia
May 2008

DEDICATION

I would like to dedicate this to my devoted wife and loving family, without whom I would not have the drive or success I possess. Thank you for the love and support you have given me and continue to give to me.

ACKNOWLEDGEMENTS

I would like to thank the Georgia Traditional Industries Program (TIP3) for the funding that provided for the planning, oversight, and completion of the three individual studies. I would also like to thank Langdale Industries, Plum Creek, Lott Logging, and Hill Logging for the resources they provided and the sacrifices they made during each study. I would further like to thank the University of Georgia Warnell School of Forestry and Natural Resources for the education and resources which they have provided during my tenure. Individually I would like to thank Dale Greene, Bob Izlar, K.C. Das, and Pete Bettinger for serving as my advisory committee, for providing guidance and knowledge, and for their overall support during and after each study. An additional thank you goes to Shawn Baker, Andres Villegas, Jim Barrett, Dan Lamontagne, Joy Peterson, and the entire staff of Langdale Company and Plum Creek's Macon, Georgia office for their hands-on support.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Conventional clearcut operations of the 1970s and 1980s harvested primarily pine and some hardwood (Stokes et al. 1985). The pine component typically had a minimum 6-inch diameter at breast height (dbh) for pulpwood and a 6-inch top minimum top for sawtimber that created large amounts of limbs, tops, and small pines as waste biomass (Miller et al. 1987). The hardwood component created even more waste biomass because only stems that had a dbh of 12 inches or greater were utilized (Stokes et al. 1984). Increasing amounts of logging residues and an abundance of unmerchantable timber with no available market was a persistent problem during this time (Sirois and Stokes 1986).

The rapidly increasing petroleum prices due to the Arab oil embargo of 1973-74 resulted in an increased demand for alternative energy sources (Stokes and Sirois 1985, Watson and Stokes 1989). Forest products companies actively searched for alternative fuel sources to feed their boilers. Mill waste was readily available and essentially free to many manufacturing facilities, but energy wood produced in the woods was also used when insufficient amounts of mill waste were available (Watson et al. 1986). This new market for fuel wood brought on by the increasing demand to reduce the use of expensive fossil fuels promoted the harvesting of logging residues and unmerchantable stems.

There were four general harvesting approaches used during the 1970s and 1980s aimed at capturing and utilizing forest residues and unmerchantable stems (Watson and Stokes 1989). The first approach was to develop equipment that could be used to harvest both residues and unmerchantable stems. Chipping, chunking, crushing, baling, grinding, shredding, mulching, and hogging were all methods used to handle the material on site to reduce handling and transportation cost (Stokes and Sirois 1989). The other three approaches were defined by when this material was harvested: preharvest operation before the conventional tree-length system, post harvest operations following the conventional tree-length system, and an integrated operation where residues and unmerchantable stems were harvested at the same time as conventional roundwood products (Watson and Stokes 1989).

Preharvest operations used various techniques ranging from in-woods chippers stationed at a loading deck to mobile chipper-forwarder-harvesters that maneuvered through a stand cutting and chipping biomass (Stokes and Sirois 1985). The most common preharvest practice used chippers along with conventional logging equipment to enter a stand and harvest unmerchantable trees before conventional roundwood products (Stokes and Sirois 1985). This two-pass system required the felling machine and skidder to cut and skid unmerchantable stems prior to conventional roundwood products. One disadvantage to the preharvest operation was limbs and tops of merchantable stems were not harvested and remained on site (Stokes et al. 1985). This system also appeared to be highly sensitive to unmerchantable biomass volumes and average piece size that could drive up felling cost when the per acre biomass volumes were low (Miller et al. 1987, Watson et al. 1986).

Operations designed to utilize tops, limbs, and unmerchantable biomass post harvest were the most difficult of harvesting approaches aimed at biomass utilization (Stokes and Sirois 1989). Unmerchantable biomass stems of varying sizes including cut and broken stems were often scattered across the harvest site making recovery difficult (Watson and Stokes 1989). This two-pass system was significantly less cost-effective than a preharvest operation or an integrated operation (Stokes and Sirois 1989).

Most southern forest harvesting systems move full trees or merchantable tree-length stems to roadside (Greene et al. 2001). These systems evolved during the 1970s when it was common for hardwood pulpwood to be left standing in the woods (no market), while a few pine products (pulpwood, chip-n-saw logs, and large sawtimber or plylogs) and large hardwood logs were typically extracted.

Multiple studies of integrated tree-length harvesting were conducted to examine the harvest of logging residues and unmerchantable trees during clearcut harvests (Miller et al. 1987, Puttock 1987, Watson et al. 1986 Stuart et al. 1981, Stokes et al. 1984). All studies identified the need for a single felling and skidding pass to most efficiently collect both merchantable and residual material. Making two passes across the site – one to collect conventional products and a second to collect forest residues – proved to be too costly.

Whole-tree chipping and whole-tree harvesting are two other integrated harvesting systems aimed at utilizing forest biomass. The improvements in flail debarking technologies during the 1980s allowed operations to produce clean pulp chips (<2% bark content) as well as a dirty chips

(>2% bark content) that could be used as fuelwood (Hammerstad et al. 1986, Lamber and Howard 1988, Stokes and Watson 1988). This system increased total tree biomass utilization from forest stands. One disadvantage to whole-tree chipping is often the lack of product separation of larger stems into higher value products. In a typical stand multiple products with varying prices can exist, but whole-tree chipping may only allow the utilization of clean pulp chips and dirty fuel chips. This system is potentially more economical in stands with small stems (Stokes and Watson 1988). Whole-tree harvesting has benefits of conventional tree-length logging in that it utilizes both solid wood products and the biomass from the limbs and tops.

Integrated harvesting systems have proven beneficial for the recovery of biomass, but some debate remains on how to allocate the cost for producing energy wood (Puttock 1995). The marginal cost approach treats the energy wood as a by product of the production of conventional products (Stuart et al. 1981, Desrochers et al. 1994). This approach essentially treats the energy wood at a cost of zero assuming no felling, skidding, or processing cost. The second approach is the joint product cost that distributes the total cost of harvesting, skidding, and process across both the conventional products and the fuel wood. This approach results in a higher fuel wood cost per unit but lowers the per unit cost for the conventional products.

Studies also showed that harvesting residues and unmerchantable stems provided other benefits such as reduced site preparation cost (Miller et al.1987, Watson et al. 1986, Ragan 1987, Watson and Stokes 1989). Watson and Stokes (1989) reported a 25% reduction in site preparation cost due to the removal of residues and unmerchantable stems. The cleaner site required less site preparation time for the shear-rake-pile-burn treatments.

Even with proven approaches for harvesting biomass alongside a conventional tree-length operation, the techniques did not become common practice in the southern United States during the late 1980s and 1990s. This was due largely to significantly lower fossil fuel prices as compared to the mid to late 1970s. Whole-tree chipping using flail processing did grow because of its potential to produced clean pulp quality chips from small diameter trees in applications such as first thinnings (Stokes 1997). However, markets for dirty whole-tree chips for energy feedstock languished during these years.

A goal of the forest products industry during the 1980s was to become more self-sufficient for their energy needs (Society of American Foresters 1979). Cogeneration power facilities allowed for this independence by utilizing biomass as a product to produce both electricity and industrial heat or steam (Miller et al. 1987).

Biomass use has grown significantly over time and is a topic for energy debates in the 21st century. In 2003 biomass contributed almost 3 percent of the total United States energy consumption (Perlack et al. 2005). The forest products industry was the largest user of biomass for energy utilizing nearly 96 million dry tons. The primary sources of this material are mill residues and pulping liquors, but they are only secondary sources of forest. The three potential primary sources of forest biomass according to the U. S. Department of Energy are logging residues, biomass removal, and fuel reduction treatments.

SUMMARY

The southern USA currently has an abundance of pine pulpwood in many areas, reflected by stumpage prices that have not increased in real terms for years. In this market, landowners and forest managers often find it difficult to have thinnings of pine plantations performed at a time that maximizes the biological response to thinning. This soft market for small trees can also lead to more selective product specifications for pulpwood, leaving smaller trees in the woods after clearcuts, which subsequently require additional site preparation steps to deal with these residual standing stems before artificial regeneration. Additional markets for currently unmerchantable small stems and for residues, such as limbs and tops, could turn what is currently a cost item into a potential revenue stream for forest landowners and reduce reforestation costs. In addition, this material could serve as a feedstock for biorefinery or biomass energy facilities.

Today's product markets and logging equipment are quite different from those common during the 1980s. For example, Watson et al. (1986) defined a "conventional" harvest as one that removed all pine stems 6 inches or greater in diameter and all hardwood stems 12 inches and greater in diameter. Hardwood pulpwood markets were weak or did not exist at that time, whereas today's hardwood pulpwood often commands a higher price and experiences more stable demand than pine pulpwood. The logging systems they examined did not employ sawhead feller-bunchers, used much smaller grapple skidders (measured by either horsepower or grapple size), did not evaluate mobile log loaders, and did not utilize mechanized delimbing (pull-through delimbers, chain flails, or grapple processors). All of this equipment is common today in southern forest operations.

Using information obtained from harvesting trials as well as tests of alternative residue sources, we evaluated the economic feasibility of using understory and logging residues. We determined the cost at which feedstock could be processed in the woods and loaded onto trucks (onboard $/ton). Economic analyses included sensitivity analyses to examine the impacts of a roundwood:chip ratio, understory biomass (tons/acre), total roundwood availability (tons/acre), skid distance (feet), chip loading time, and system fuel cost on onboard cost ($/ton) and production (tons/smh) of roundwood and chips.

The main objective of this research was to obtain good harvesting information from integrated tree-length harvesting systems aimed at recovering logging residues and understory biomass. More specifically we wanted to gather information on harvesting production, site preparation trade-offs, and potential cost of alternative biomass products, so we could fully examine the economics associated with greater use of biomass products from forests in the South.

CHAPTER 2

FOREST BIOMASS RECOVERY BY ADDING SMALL CHIPPERS TO TREE-LENGTH HARVESTING SYSTEMS IN PLANTED PINE STANDS OF THE SOUTHERN USA

Westbrook, M.D. Jr., Greene, W.D., Baker, S.A., Izlar, R.L., Das, K.C., Bettinger, P., To be submitted to *Biomass and Bioenergy*

ABSTRACT

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INTRODUCTION

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METHODS

Site Characteristics

The addition of a small chipper to a tree-length harvesting system was examined in three replicated studies across Georgia with multiple harvesting treatments within each study.
Each study had slight differences in species, stand location, stand age, and harvest treatments (Table 1). The first study (2006 clearcut) took place in a 33-year old slash pine (*Pinus elliottii*) plantation that had been thinned once on a flatwoods site in Echols County, Georgia. The stand received a clearcut harvest during the study. The second study (2007 thinning) utilized a slash pine plantation on a lower coastal plain site in Brooks County, Georgia. This stand was 16 years

old and received a first thinning harvest during the study. The third study (2007 clearcut) was conducted during a clearcut harvest of a loblolly pine (*P. taeda*) stand on an upper coastal plain site in Jones County, Georgia. The stand was 28 years old and had been thinned twice.

Table 1. Summary of information for each study site and stand characteristics.

County, State	Year	Harvest Type	Species	Age	Treatment
Echols, Georgia	2006	Clearcut	Slash Pine	33	A,B,C
Brooks, Georgia	2007	Thinning	Slash Pine	16	B,C
Jones, Georgia	2007	Clearcut	Loblolly Pine	28	A,B,C,D

In each study the tract was divided into multiple blocks where different treatments were replicated. The 2006 clearcut divided the tract into 9 blocks (3 replications of 3 treatments), each about 20 acres in size to allow approximately five working days for the contractor to clearcut. During the 2007 thinning study the tract was divided into 6 blocks (3 replications of 2 treatments) with each block about 13 acres in size, permitting approximately three days of harvesting. Lastly, the 2007 clearcut study divided the tract into 12 study blocks (3 replication of 4 treatments) of about 13 acres that were harvested in about three days per block.

Equipment Profiles

The 2006 clearcut and 2007 thinning studies were conducted cooperatively with Langdale Industries – a major privately owned forest products company – and Lott Logging Inc., an independent logging contractor. Lott Logging leased a Conehead 565 chipper during the 2006 clearcut study and afterward purchased a Conehead 570 chipper that was used during the 2007 thinning study. The Conehead 565 (570) chipper has a 260 (325) horsepower Cummins turbocharged diesel engine, a 21” (22) diameter capacity, and a feed rate of 100 feet per minute. Neither of the Conehead models included an infeed deck, thus the loader had to feed the chipper material directly. In addition to the chipper, Lott operated a Tigercat 718 feller-buncher, a John Deere 640D grapple skidder, and a Prentice 280 loader with a pull-through delimber. Lott Logging typically performed thinnings, delimbed with a delimbing gate and the loader-mounted delimber, and set out loaded trailers for hauling by both owned and contract trucks. Their operation is very typical of ground-based, mechanized tree-length pine systems operated across the U.S. South.

The 2007 clearcut study was conducted with the help of Plum Creek – the largest landowner in the United States – and Hill Logging, Inc., one of their final harvest contractors. During the 2007 clearcut study Hill Logging leased a Woodsman 334 chipper. The Woodsman 334 is powered by a 400-horsepower turbo diesel and has a 22-inch diameter capacity. The Woodsman chipper also featured a short infeed deck that permitted a loader to drop material on it and resume other duties which the chipper fed itself. Hill utilized a crew composed of one Timberjack 724D feller-buncher, two John Deere 684 grapple skidders, two Tigercat 230 loaders, one Tigercat 240 mobile loader, and two John Deere 2054 shovels with Waratah 622 processor heads. This system was not a conventional tree length system, but moved tree-length stems to roadside where the Waratah processors produced a mix of tree-length stems and cut logs.

Treatments

During the three studies, four different treatments were used (Table 1). Treatment A used the conventional ground-based tree-length harvesting system with no attempt to harvest limbs, tops, or unmerchantable stems. Treatment B employed the conventional harvesting system with the addition of a small chipper to chip all limbs and tops. Treatment C used the conventional system with the addition of the chipper to chip limbs, tops, and all non-merchantable woody biomass between one and four inches diameter at breast height (dbh) that could be harvested by the feller-buncher and skidder. Treatment D was added during the 2007 clearcut study and was a modification of Treatment B. Trees were delimbed to approximately 5-inch top diameters then topped to keep most limbs attached to the tree top. The 2006 clearcut used treatments A, B, and C; the 2007 thinning study used only treatments B and C; and the 2007 clearcut study used treatments A, B, C, and D. Treatments were randomly assigned to study blocks.

Preharvest Biomass Estimates

To estimate unmerchantable biomass on study blocks before harvesting, we used a systematic cruise with 0.05-acre circular plots located on a 4-chain by 4-chain grid across each block. In each plot we tallied all unmerchantable stems, defined as woody stems of any species with a dbh between one and four inches and total height of at least eight feet. Species, dbh, and total height were recorded for each stem within a plot. We used individual stem weight equations to estimate total green weight tons of biomass (Franchi et al. 1984).

Harvest Mix

The blocks were harvested according to treatment. For example, in the 2006 clearcut study, all treatment B blocks were harvested, followed by all treatment C blocks, then treatment A blocks. This minimized the time the chipper had to be leased and the number of times the crew had to change treatments. Each study block assigned treatment A or B had a work sample collected during one full day of operation while treatment C and D blocks had two days monitored. Daily production in loads and tons was collected for each product class (e.g., pulpwood, sawtimber, chips, etc.) harvested on each block. Daily fuel usage and equipment operating hours were recorded by the contractor for each piece of woods equipment. A 5-gallon chip sample was collected on each study block and sealed for transport to a lab. A subsample of these chips were weighed, dried, and re-weighed to obtain moisture content, particle distribution, and bulk density. Chips were also evaluated to determine their elemental content (N, P, and K) and their potential heat content per unit of dry weight.

Sensitivity Analysis

Using a modified version of the Auburn Harvesting Analyzer we developed a base case model (Attachment A). The base case model was used to perform sensitivity analysis for Treatment A. The base case model was further adjusted to represent Treatment B (Attachment B) and Treatment C (Attachment C). The models all used the same machine rate parameters (Attachment D). The two models used to represent chipped treatments also include chipper parameters. The chipper was assumed to have a purchase price of $160,000, operational life of 5 years, and a residual salvage value of 20% of the purchase price. We assumed interest, insurance, and taxes for all equipment to be 8%, 1%, and 2%, respectively, of the average annual investment. The maintenance and repairs cost were assumed at 100% of depreciation. Off-road diesel prices ranged from around \$2.50 to \$3.00 per gallon during these studies, thus we assumed a price of \$2.75 per gallon for our cost estimates. We assumed the chipper would have 90% mechanical availability. Chips were hauled from the woods at an assumed cost of \$0.12 per ton-mile and a 40 mile haul distance. For Treatments B and D, chip cost per ton only included the cost of the chipper and loader costs associated with feeding the chipper. For Treatment C, chip costs also include a proportioned cost of felling and skidding as this treatment required additional felling and skidding of understory stems to perform.

The model was used to predict a variety of cost and production outputs in response to a series of inputs including roundwood:chip ratio, understory biomass (tons/acre), total available roundwood (tons/acre), skid distance (feet), roundwood loading time (min), and fuel cost (US\$/gallon). The outputs we evaluated were hourly production (tons/smh) and onboard cost (\$/ton) of both roundwood and chips.

Site Preparation Benefits

After the 2006 clearcut we were able to evaluate site preparation cost based on harvest treatments. The cost of raking each site prior to regeneration was monitored on each harvest block by Langdale personnel. After raking and bedding were completed, we tallied and measured each debris pile created by the raking operation. We measured the width of each pile in two perpendicular directions and also measured the height of each pile. Area of each pile was estimated assuming the base of the pile was ellipsoidal and a volume index was computed assuming the entire pile was conical in shape. The area and volume indices were used to quantify the logging residues that remained and the area that could not be planted due to their presence.

RESULTS

Preharvest Understory Biomass Estimates

The 2006 clearcut study site averaged 220 stems per acre with an average dbh of 2.0 inches that comprised 7.7 tons per acre of understory biomass (Table 2). The 2007 thinning study had approximately 796 stems per acre with an average dbh of 2.2 inches resulting in 26.3 tons per acre of understory biomass. The 2007 clearcut study found 185 stems per acre with an average dbh of 1.7 inches that comprised 3.7 tons per acre. Note that the greatest understory volume was found on the unthinned stand that was receiving a first thinning while the least biomass was found on the stand where two thinnings had previously taken place.

Table 2. Preharvest understory biomass (1-4 inch dbh) estimates for three biomass harvesting studies using a small chipper added to a mechanized tree-length operation.

Study	Trees/acre	DBH, in.	Tons/Acre
2006 Clearcut	220	2.0	7.7
2007 Thinning	796	2.2	26.3
2007 Clearcut	185	1.7	3.7

Production per Acre

In the 2006 clearcut study, 2007 thinning study, and the 2007 clearcut study production of roundwood per acre did not differ significantly by treatment at the 5% significance level (Figure 1). However, chip production per acre did vary by treatment over the three studies. The 2006 clearcut Treatment B recovered an average of 3.8 green tons of chips per acre compared to 10.8 green tons recovered by Treatment C, a significant difference at the 10% level, but not at the 5% level (Figure 2). The difference between these two treatments, approximately 7 green tons/acre, compared favorably with our preharvest estimate of available understory biomass (7.7 green tons/acre). The 2007 thinning had a significant difference in chip production per acre between Treatment B and Treatment C at the 5% significance levels (Figure 2). Treatment B recovered approximately 3.1 green tons per acre of limbs and tops while Treatment C recovered 20.1 green tons per acre of limbs, tops, and understory stems. Of the 20.1 green tons per acre, approximately 3.1 tons were limbs & tops, leaving 17 tons as understory stems. Since 26.3 tons of understory was inventoried before harvesting, it appears that about 65% of the standing unmerchantable stems were harvested and captured in biomass chips. Lastly the 2007 clearcut study chip production (tons/acre) varied significantly by treatment at the 5% significance level (Figure 2). Treatment B recovered 4.9 green tons per acre which was significantly less than Treatment C (16.8 green tons/acre) but was not different from Treatment D (8.7 green tons/acre). Treatment D was also not significantly different from Treatment C. Treatment D per acre chip production was not significantly different from Treatment B because of the high variability on blocks. The almost 12 tons per acre of understory biomass recovered (16.8 – 4.9) was three times greater than our preharvest estimates. This increased tonnage was gathered from areas considered inaccessible and not included in the preharvest inventory.

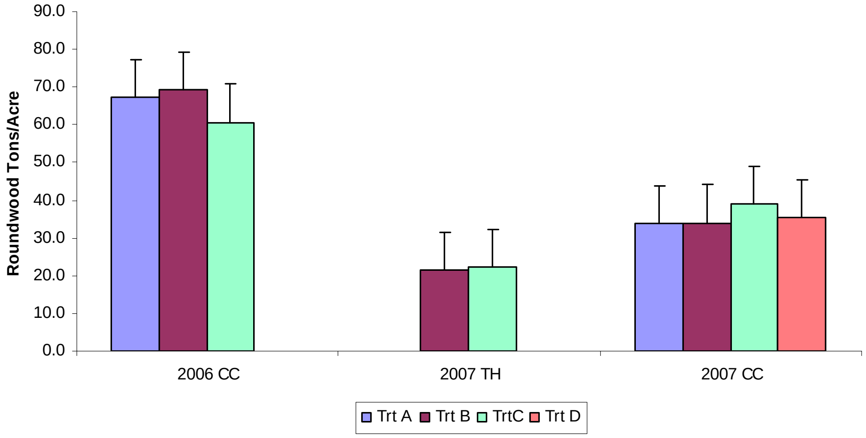

Figure 1. Roundwood production per acre by harvest type and treatment in three studies of a small chipper added to a tree-length harvesting system.

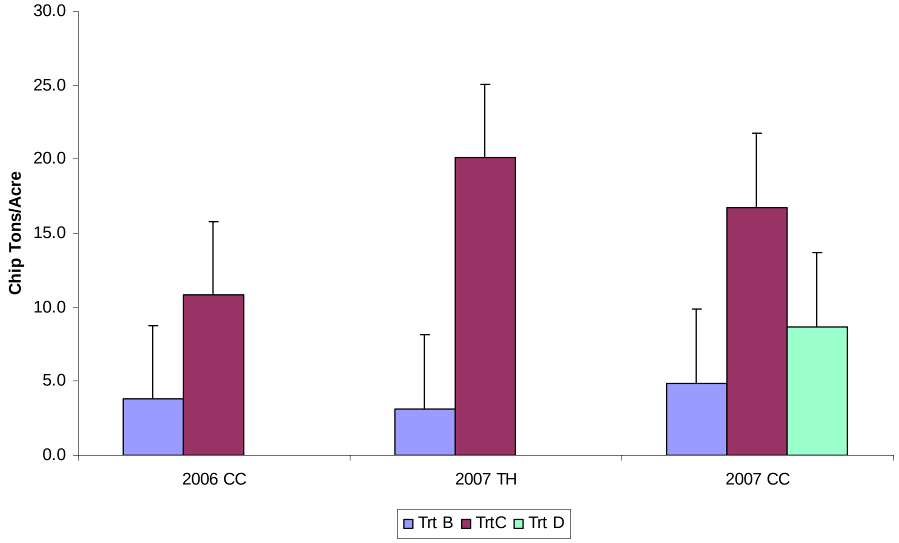

Figure 2. Chip production (tons/acre) by harvest type and treatment in three studies of a small chipper added to a tree-length harvesting system.

Roundwood Production per Scheduled Hour

In the 2006 clearcut study, roundwood production rates were similar across treatments with no significant differences found in hourly production at the 5% significance level (Figure 3). The 2007 thinning study produced significantly less roundwood per smh in Treatment C as compared to Treatment B at the 5% significance level (Figure 3). This 50% reduction in roundwood per smh was primarily due to the large amount of understory biomass between 1-4 inches dbh harvested in Treatment C. Roundwood production per smh in the 2007 clearcut study varied significantly by treatment at the 5% significance level (Figure 3). Treatment A produced significantly more roundwood per smh than Treatment B, but not significantly more than Treatment C or Treatment D. Treatment B was also not significantly different from Treatment C or Treatment D. The loss in roundwood production on Treatment B was probably the result of wet weather and road conditions experienced during the harvesting of the treatment blocks.

Attachment E, F, and G are summarized production tables by block and treatment for the 2006 clearcut, 2007 thinning, and the 2007 clearcut studies, respectively.

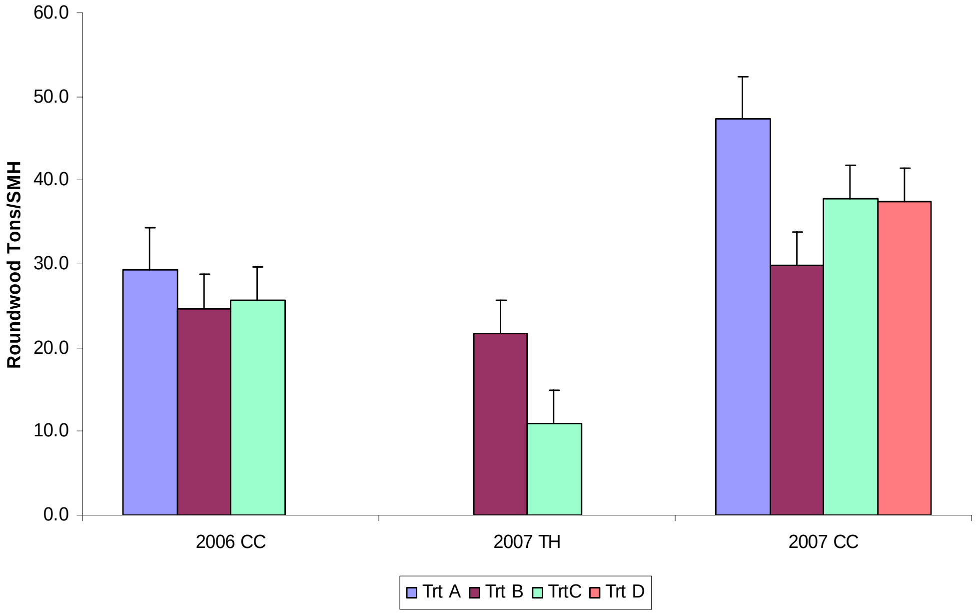

Figure 3. Roundwood production (tons/smh) by harvest type and treatment in three studies of a small chipper added to a tree-length harvesting system.

Chip Production per Scheduled Hour

Chip production per smh varied by treatment and by study. The 2006 clearcut study produced significantly less chips in Treatment B (1.3 green tons/smh) as compared to Treatment C (4.7 green tons/smh) at the 5% significance level (Figure 4). Again during the 2007 thinning study there was a significant difference in chip production with 3.1 green tons per smh produced during Treatment B and 9.5 green tons per smh produced during Treatment C. Chip production per smh during the 2007 clearcut study was significantly different between treatments. Treatment B (4.3 green tons/smh) was significantly lower than Treatment D (9.1 green tons/smh) which was significant lower than Treatment C (15.4 green tons/smh). Harvesting understory biomass along with limbs and tops significantly increased chip production per smh in both the clearcut and thinning operations.

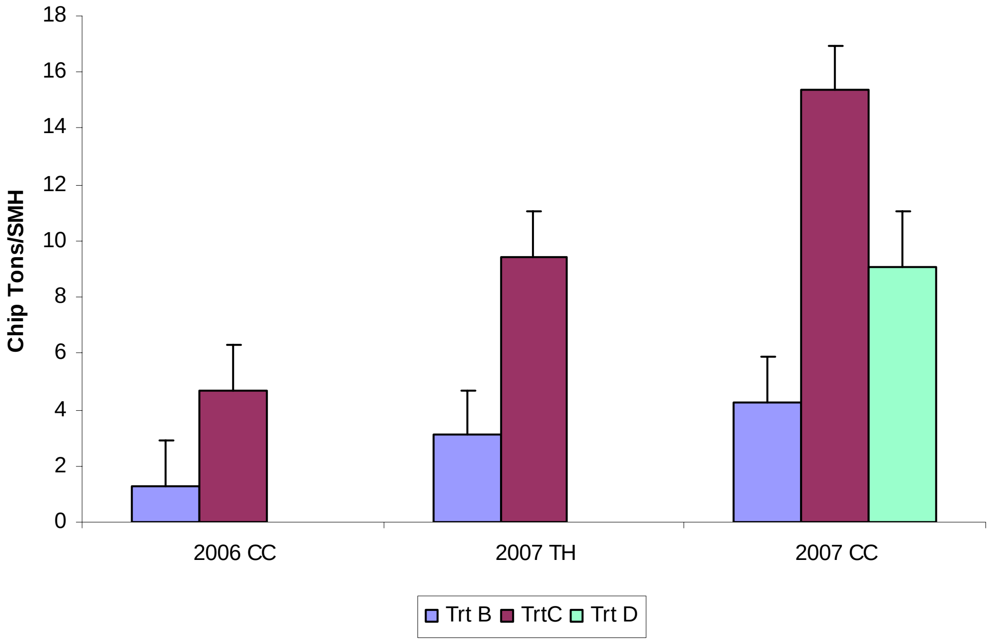

Figure 4. Chip production (tons/smh) by harvest type and treatment in three studies of a small chipper added to a tree-length harvesting system.

Total Tons per Scheduled Hour

Increased chip production for Treatment B and Treatment C during the 2006 clearcut did not significantly increase the total tons per smh (roundwood + chips) at the 5% significance level (Figure 5). The 2007 thinning study produced significantly less roundwood and significantly more chips per smh, but there was no significant difference in total tons per smh between treatments at the 5% level (Figure 5). The increased tonnage per smh on Treatment C came from the high levels of understory biomass. During the 2007 thinning the crew was able to produce equivalent total tons per smh between treatments, but Treatment C produced more of the lower value biomass chips at the expense of roundwood. The significantly less roundwood produced in Treatment B, and the significantly greater biomass recovered per acre in Treatment C resulted in

Treatment B producing significantly less total tons per smh than Treatment C at the 5% level during the 2007 clearcut (Figure 5). Treatment B was however not significantly different from Treatment A and Treatment D producing 34.2, 47.3, and 46.4 total tons per smh, respectively. Also, Treatment C (total tons/smh) was not different from Treatment A and Treatment D.

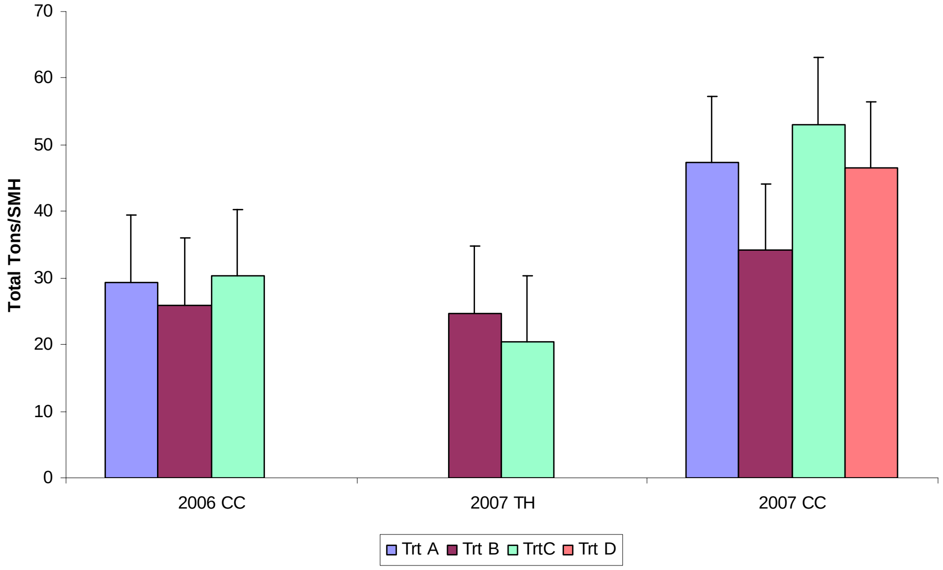

Figure 5. Total production of roundwood and chips per smh by harvest type and treatment in three studies of a small chipper added to a tree-length harvesting system.

Adding the chipper to the two clearcut studies did not significantly reduce roundwood production (tons/smh). While not significant it did however reduce roundwood production by 14% in the 2006 study and 18-39% in the 2007 study. Also the clearcut studies indicated that the additional removal of understory did not further reduce production but rather slightly increased total production per smh over that of limbs and tops (Figure 5). Total productivity per smh for both roundwood and chips increased in Treatment C during the clearcut studies. Adding understory removals during the 2007 thinning study significantly reduced roundwood production from that with limbs and tops only chipped, but overall production of roundwood and chips per smh was similar.

Using a roundwood:chip ratio to compare production, the 2006 clearcut study produced a ton of chips for every 18 tons of roundwood in Treatment B and a ton of chips for every 5 tons of roundwood in Treatment C (Figure 6). The roundwood:chip ratio for Treatment B would be closer to 12:1 if the results from block 2 were excluded where wet weather required the use of some logging slash for an operating mat. Treatment B and Treatment C produced 9 tons and 7 tons, respectively during the 2007 thinning study for every one ton of chips. However, the roundwood:chip ratio for Treatment C was a ton of chips for every 1 ton of roundwood compared to a ton of chips for every 7 tons of roundwood for Treatment B (Figure 6). The roundwood:chip ratios during the 2007 clearcut study were a ton of chips for every 6 tons of roundwood in Treatment B, every 3 tons of roundwood in Treatment C, and every 4 tons of roundwood in Treatment D (Figure 6).

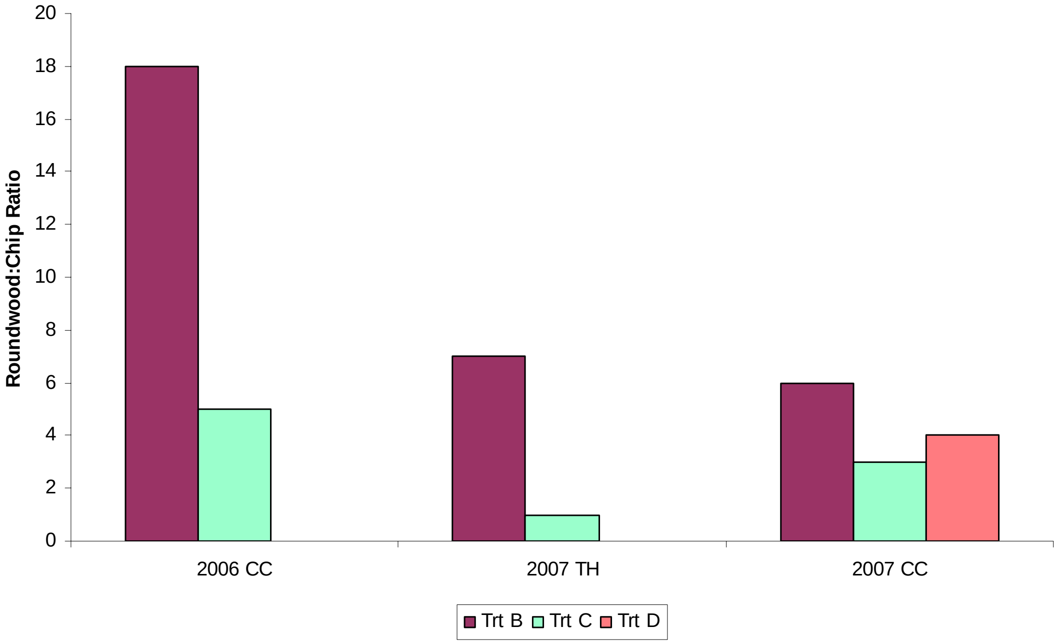

Figure 6. Roundwood to chip ratio by harvest type and treatment in three studies of a small chipper added to a tree-length harvesting system.

Fuel Consumption per Ton

Fuel consumption (gallons/ton) of woods equipment (felling, skidding, and loading) was not significantly higher for the chipper treatments than the roundwood treatments in either of the two clearcut studies (Figure 7). There was not a significant difference between conventional logging (Treatment A) and any of the chipping treatments (B, C, or D) during a clearcut final harvest. The 2006 clearcut study and 2007 clearcut study consumed an average of 0.41 and 0.58 gallons of diesel per ton of wood, respectively, for the felling, skidding, and loading activities. The 2007 thinning study required significantly more fuel per ton for the woods equipment during Treatment C (0.91 gallons/ton) as compared to Treatment B (0.58 gallons/ton).

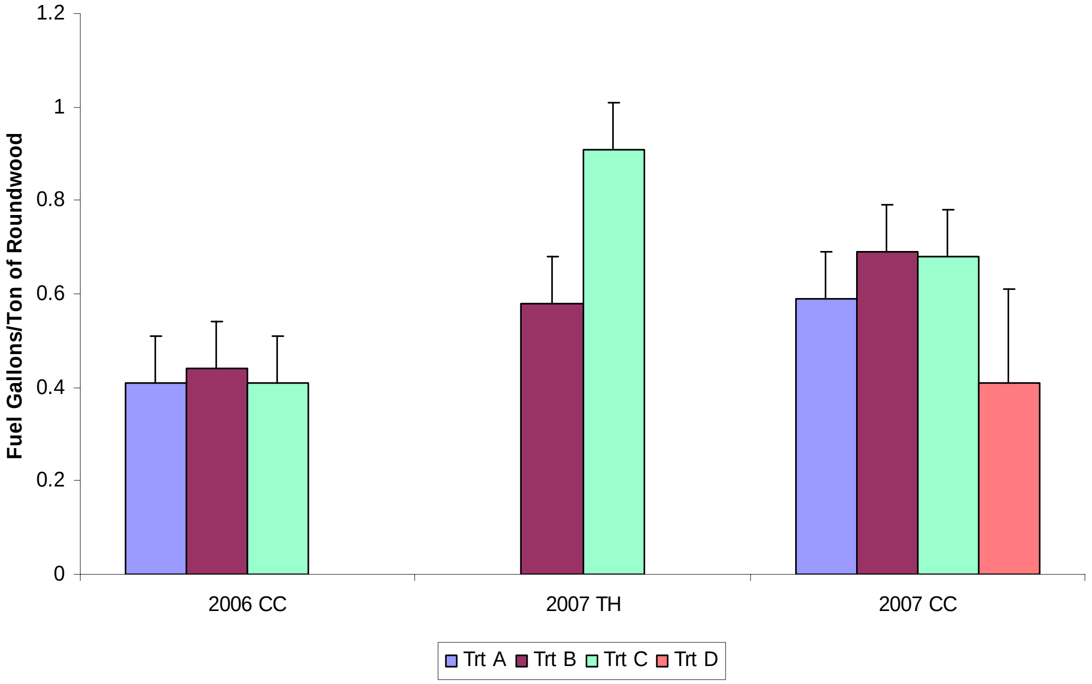

Figure 7. Fuel consumption in gallons per ton of roundwood by harvest type and treatment in three studies of a small chipper added to a tree-length harvesting system.

Producing a ton of chips required an additional 0.40, 0.46, and 0.44 gallons per ton for chipping in the 2006 clearcut, 2007 thinning, and 2007 clearcut studies, respectively (Figure 8). Thus a ton of chips required a total 0.83 gallons of diesel in the 2006 clearcut study, 1.19-1.22 gallons of diesel in the 2007 thinning study, and 1.02 gallons of diesel in 2007 clearcut study.

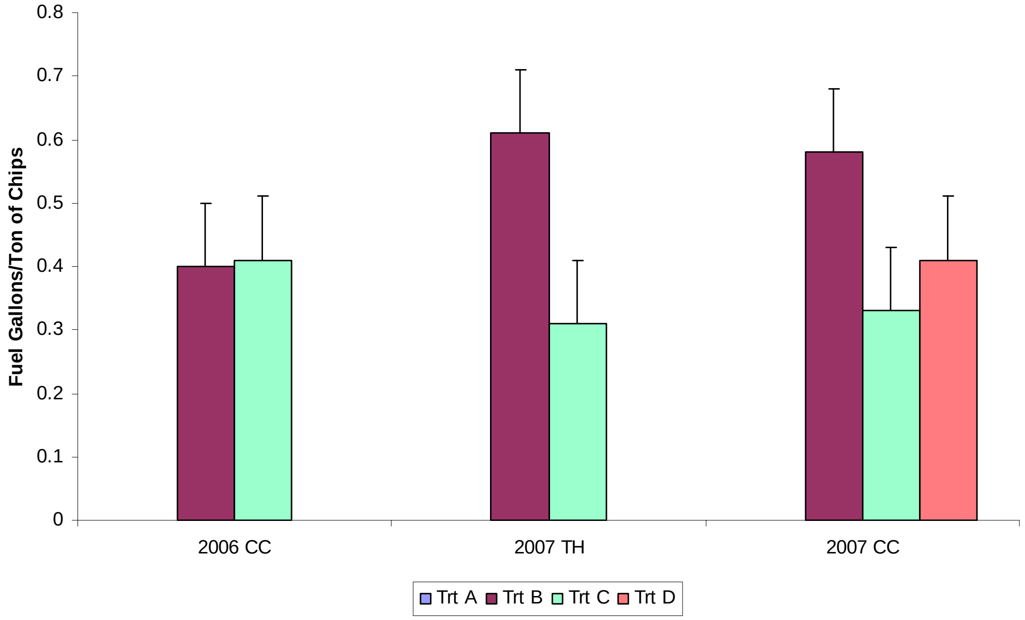

Figure 8. Fuel consumption in gallons per ton of chips by harvest type and treatment in three studies of a small chipper added to a tree-length harvesting system.

Sensitivity Analysis

The sensitivity analyses of our treatment models produced production (tons/smh) and onboard cost ($/ton) comparisons for both roundwood and chips during a clearcut harvest. As the roundwood:chip ratio increased, the roundwood production for both Treatment B and Treatment C increased. The model indicated that during a clearcut harvest, roundwood production was similar for Treatment C and Treatment A when the roundwood:chip ratio was greater than 4:1 (Figure 9). Roundwood production for Treatment B was not similar to Treatment A until the roundwood:chip ratio reached 14:1. Treatment B production was less than Treatment C for all roundwood to chip ratios. When roundwood:chip ratios were high, chip production per smh for both Treatment B and Treatment C were low. Chip production declined steeply initially, but stabilized as ratios approached 9:1.

Roundwood onboard cost increased for Treatment C and decreased for Treatment B as the roundwood:chip ratio approached 4:1 where the cost for both treatments remained flat (Figure 10). However, Treatment C had a lower onboard cost per ton than Treatment A and Treatment B which were similar. Chip onboard cost per ton increased for both treatments as ratios increased from 2:1 with Treatment C increasing at a greater rate than Treatment B (Figure 9).

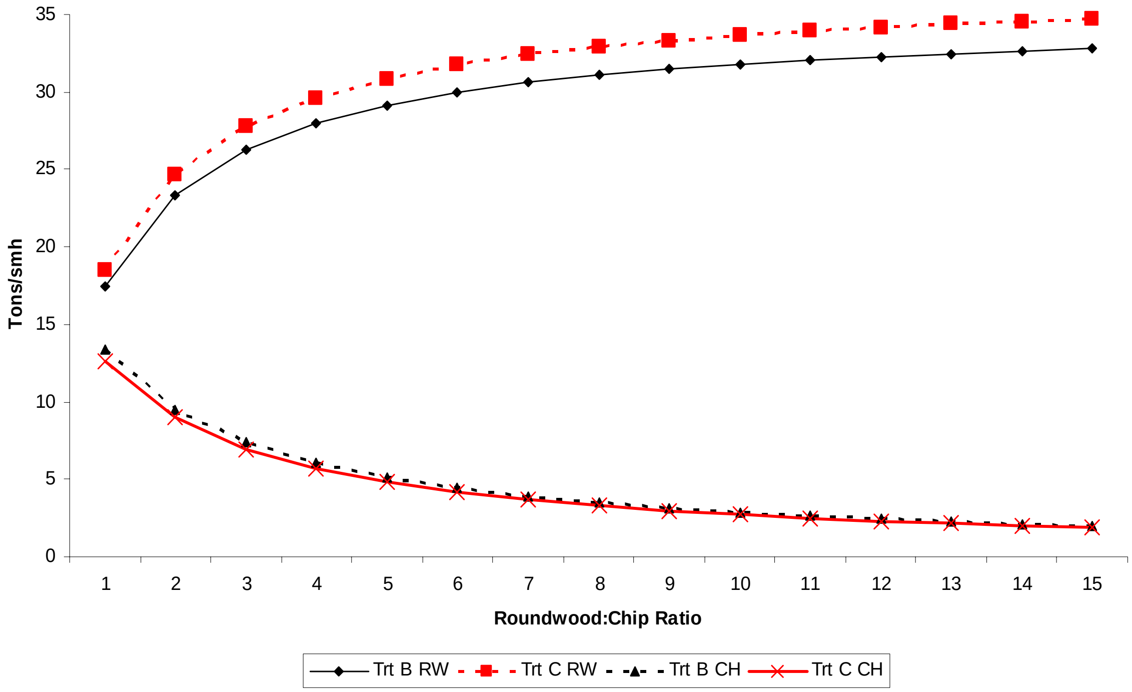

Figure 9. Roundwood and chip production (tons/smh) by treatment for increasing roundwood:chip ratios.

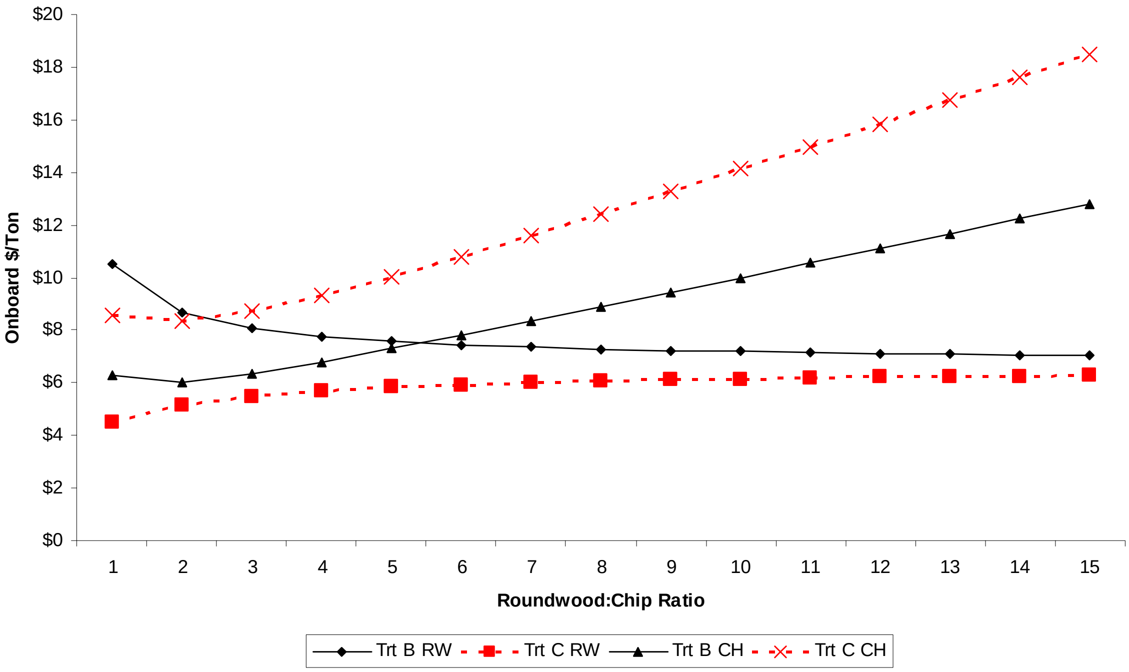

Figure 10. Roundwood and chip onboard cost ($/ton) by treatment for increasing roundwood:chip ratios.

Varying understory biomass had significant impacts on operations as seen during the 2007 thinning, so understory biomass was tested to identify the effects on production and cost for Treatment C. As understory biomass increased from 5 tons per acre, roundwood productivity decreased almost linearly from 35 tons per smh in Treatment C (Figure 11). Chip production had an inverse relationship to roundwood production. It increased almost linearly from 2.5 tons per smh as understory biomass increased from 5 tons per acre. Roundwood onboard cost per ton also decreased almost linearly from $6 per ton as understory biomass increase from 5 tons per acre (Figure 12). The onboard cost per ton of chips decrease sharply from around $16 per ton as understory biomass increased from 5 tons per acre but began to flatten out at $10 per ton as understory biomass level exceeded 13 tons per acre.

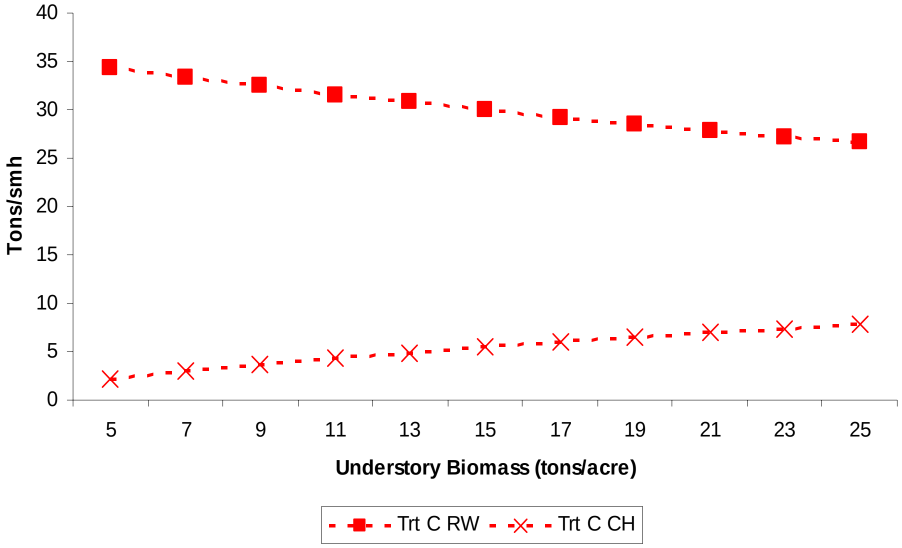

Figure 11. Roundwood and chip production (tons/smh) during Treatment C for increasing understory biomass (tons/acre) estimates.

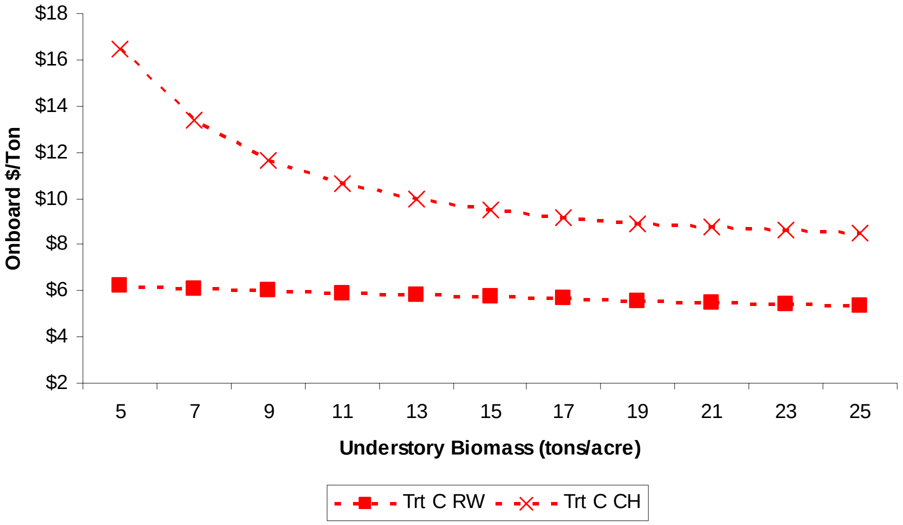

Figure 12. Roundwood and chip onboard cost ($/ton) for increasing understory biomass (tons/acre) estimates.

Total roundwood tons per acre was used in the model to test its influence on production and cost. Roundwood production per smh increased for all treatments as total tons available per acre increased (Figure 13). At around 55 total tons available per acre, roundwood production for all treatments stabilized at around 35 tons per smh with Treatment A having the highest production rate followed by Treatment B and Treatment C. Total roundwood tons available per acre did not have an effect on chip tons per smh for Treatment B, but did increase chip production slightly to 5 ton per smh for Treatment C when total available roundwood reached 45 tons per acre.

Roundwood onboard cost per ton subsequently decreased from about $20 per ton to $6.50 per ton in Treatment B and about $16 per ton to $5.50 per ton in Treatment C as total tons available per acre increased (Figure 14). Onboard cost per ton of roundwood stabilized after 55 total tons available per acre. Treatment C, which used the joint cost approach, continued to have the lowest roundwood onboard cost per ton of all treatments followed by Treatment A and Treatment B. The onboard cost per ton of chips decreased for Treatment C from about $24 per ton to about $11 per ton as total roundwood tons available per acre exceeded 45.

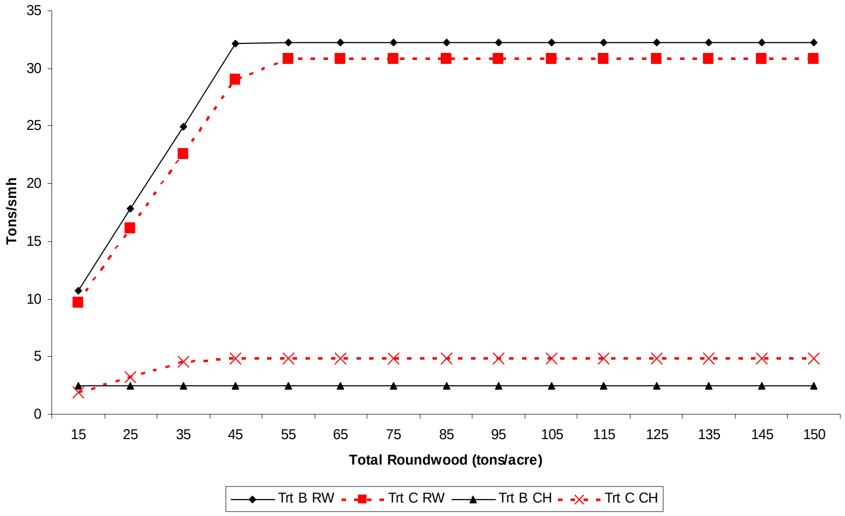

Figure 13. Roundwood and chip production (tons/smh) by treatment for total available roundwood (tons/acre) estimates.

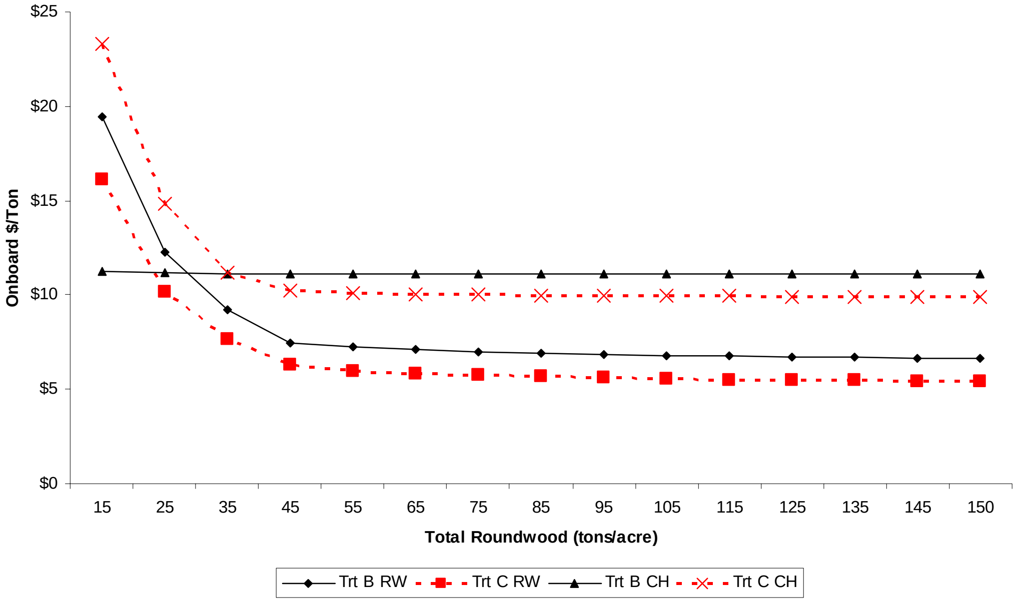

Figure 14. Roundwood and chip onboard cost ($/ton) by treatment for total available roundwood (ton/acre) estimates.

Using skid distance as an input variable to test roundwood productivity, production began to decrease from about 45 tons per smh for both Treatment A and Treatment B at around 400 feet (Figure 15). Treatment C, which had lower roundwood productivity (36 tons/smh) than Treatment A and Treatment B initially, began to decrease in production as skid distance approached 700 feet. Production for all three treatments declined at a similar rate as skid distance exceeded 700 feet with Treatment C being slightly lower than Treatment A and Treatment B. Chip production in tons per smh did not appear to be affected for Treatment C (5 tons/smh) or Treatment B (2 tons/smh) until skid distances exceeded 1500 feet where production declined slightly. Treatment C however continued to have a higher productivity than Treatment B over all tested skid distances.

Decreased roundwood production with skid distance in excess of 400 feet resulted in an increase in roundwood onboard cost per ton for both Treatment A ($6/ton) and Treatment B ($6/ton) (Figure 16). Treatment C ($5/ton) did not experience an increase in roundwood onboard cost until skid distance approached 600 feet. All treatments experienced increased roundwood onboard cost as skid distance increased with Treatment C being the lowest and increasing at a slightly lower rate than Treatment A and Treatment B. Chip onboard cost per ton continued to be lower for Treatment C ($10/ton) as compared to Treatment B ($11/ton) until skid distance reached 1700 feet (Figure 16).

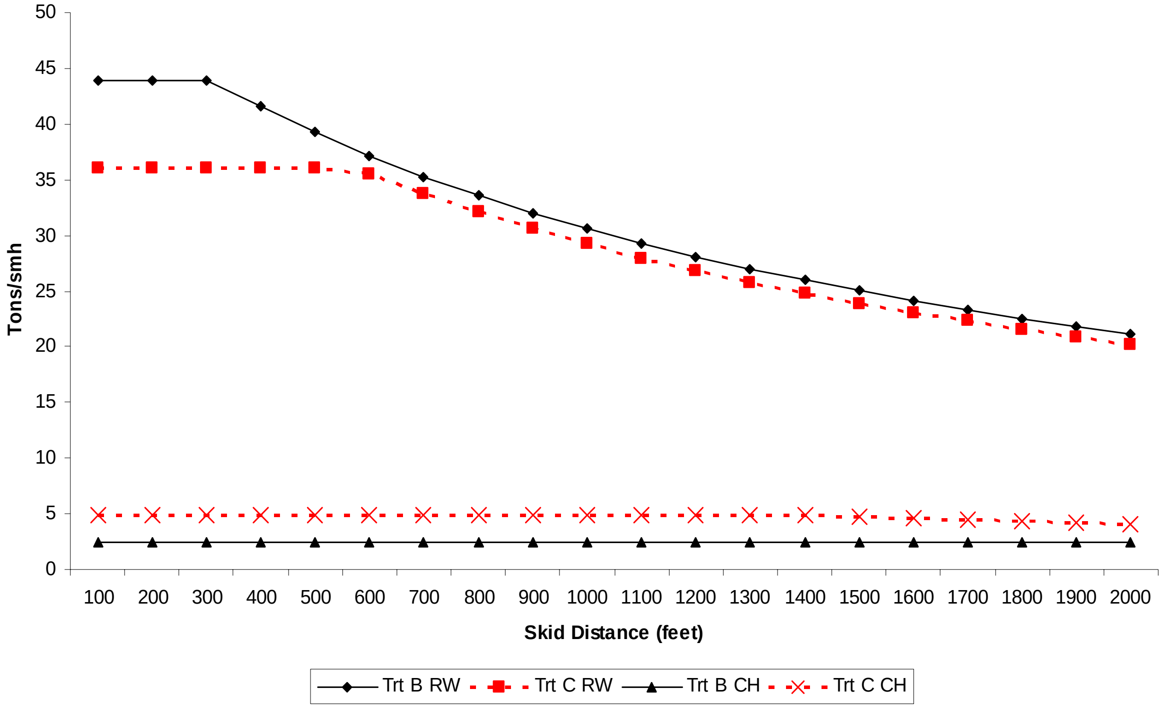

Figure 15. Roundwood and chip production (tons/smh) by treatment for increasing skid distances (feet) estimates.

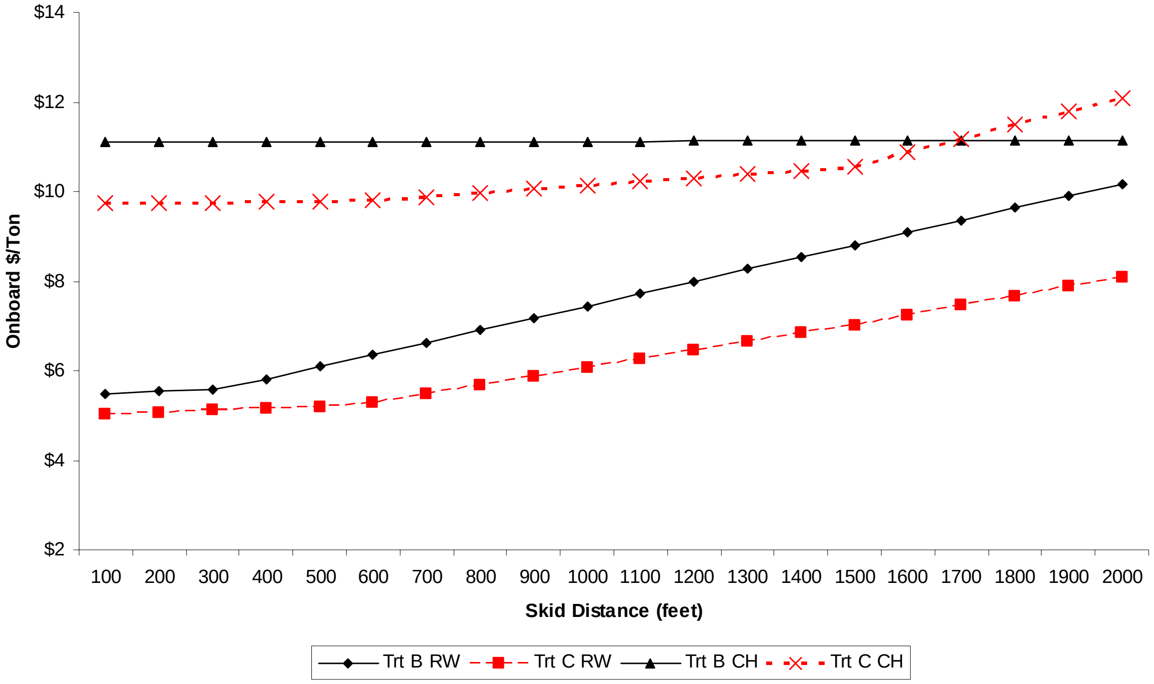

Figure 16. Roundwood and chip onboard cost ($/ton) by treatment for increasing skid distance (feet) estimates.

Roundwood production is largely influenced by the time required for a loader to load a truck. When a loader operator has to split time between processing roundwood and chips there is a possibility to negatively influence roundwood production. It was therefore important to see how chip loading time affected productivity and cost. The model indicated that as chip loading time increased Treatment B roundwood was unaffected, but roundwood in Treatment C decreased rapidly from 31 tons per smh when loading chip vans required more than 25 minutes (Figure 17). Chip production was relatively unchanged for Treatment B and decreased slightly from 5 tons per smh for Treatment C as chip loading time increased.

Decreased roundwood production in Treatment C due to extended chip loading times created an increased onboard cost for both roundwood and chips (Figure 18). Roundwood onboard cost increased at approximately $1.00 per ton every 10 minutes after an initial 25 minutes in

Treatment C. Chip onboard cost increased for both Treatment B ($0.70/ton) and Treatment C ($1.50/ton) every 10 minutes after chip loading time exceeded 25 minutes.

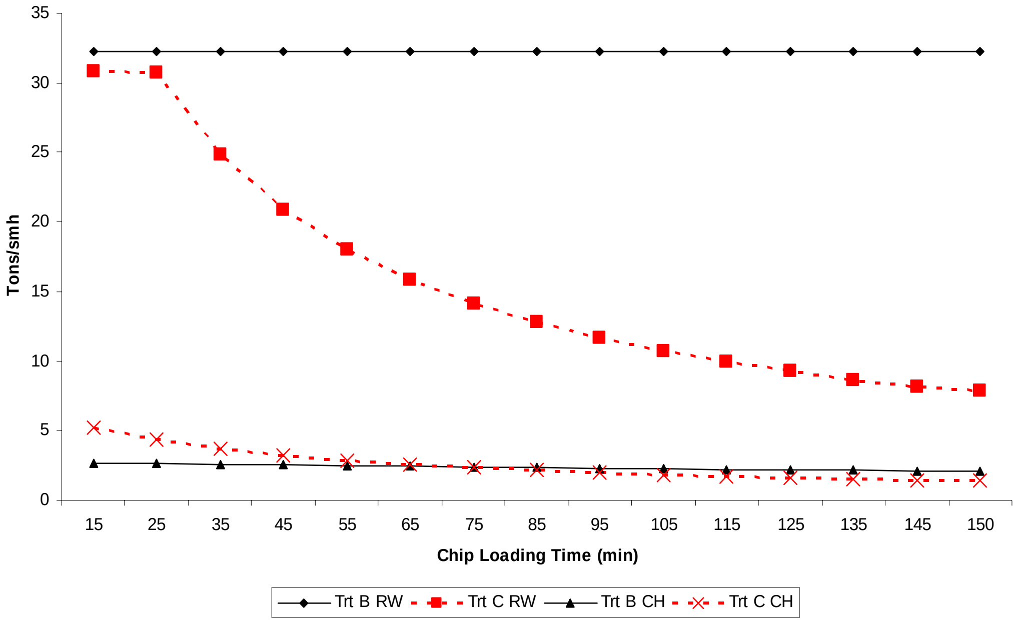

Figure 17. Roundwood and chip production (tons/smh) by treatment for increasing chip loading time (minutes) estimates.

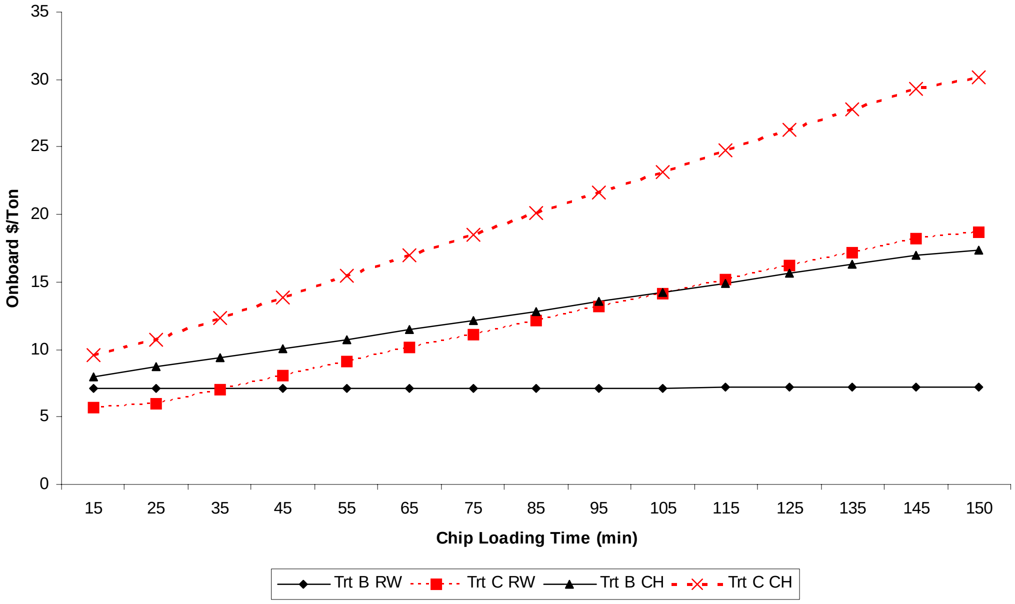

Figure 18. Roundwood and chip onboard cost ($/ton) by treatment for increasing chip loading time (min) estimates.

With the highly variable fuel cost experienced during these studies, it was important to examine the effect fuel cost had on roundwood and chip cost. Fuel cost increased onboard cost almost linearly with a similar per ton impact on all treatments (Figure 18). For every $1.00 increase in fuel cost Treatment B experienced a $0.60 increase in onboard cost of roundwood and Treatment C experienced a $0.73 increase in onboard cost of roundwood. Increasing fuel cost also had a linear increase on chip onboard cost per ton for both treatments. Chip onboard cost increased $0.40 for Treatment B and $0.33 for Treatment C for every $1.00 increase in fuel cost.

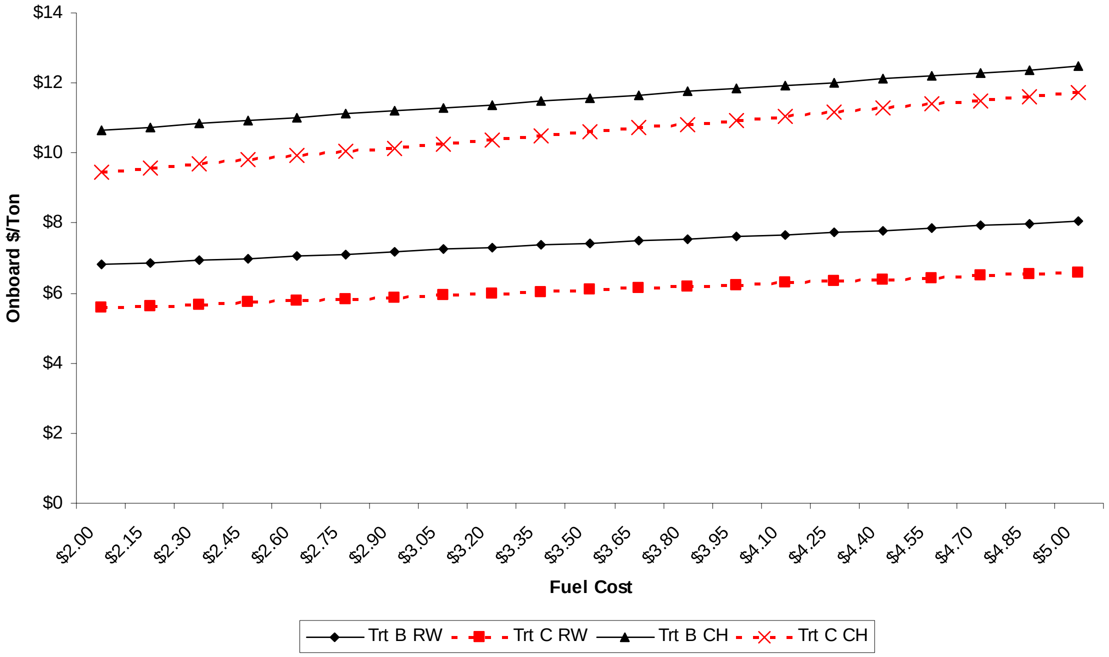

Figure 19. Roundwood and chip onboard cost ($/ton) by treatment for increasing fuel cost (US$/gallon).

Chip Properties

Green chips averaged approximately 45% moisture content in the 2006 clearcut study and 41% in the 2007 thinning study (Table 3). Lab analyses showed the chips to be primarily carbon with approximately 51% of green chips in carbon by weight in both studies. The chips also had heating values of 8,200 BTU/lb in the 2006 clearcut study and 8,400 BTU/lb in the 2007 thinning study. These heating values are comparable to those reported for other forms of woody biomass (McKendry 2002).

A concern often expressed about utilization of logging residues involves nutrient removals from the site. Foliage and small limbs contain a disproportionate amount of nitrogen (N), phosphorous (P), and potassium (K). Our chip analyses indicated higher percentages of N, P, and K in chips from Treatment C than in chips from Treatment B (Table 3). Results from our chip analyses combined with the tons removed per acre suggest that in the most intensively harvested Treatment C blocks less than 24 lb/ac of N was removed in the 2006 clearcut study and 153 lbs/ac in the 2007 thinning study. Removals of P and K were approximately 2.5 lb/ac and 7.1 lb/ac, respectively, in Treatment C during the 2006 clearcut study and 0.76 lb/ac of P and 0.48 lb/ac of K, respectively, in Treatment C during the 2007 thinning study.

Nutrient losses associated with Treatment B in the 2006 clearcut study were estimated at 6.5 lb/ac of N, 0.5 lb/ac of P, and 1.7 lb/ac of K. These values were slightly higher than the removal from Treatment B during the 2007 thinning which were 4.3 lb/ac of N, 0.05 lb/ac of P, and 0.04 lb/ac of K. Annual atmospheric deposition of nitrogen through rainfall and particulate matter is 5.9 lbs per acre per year (Boring *et al.* 1988). Carter and Foster (2004) state that 0.4 lbs P and

1.5 lbs K are average annual inputs per acre. Overall, removal during the first study of material from Treatment B was replenished from annual atmospheric deposition in about one year and in about five years for Treatment C. The 2007 thinning study had higher removal amount (lb/ac) of nitrogen, but the percent was relatively similar to the first study.

Table 3. Properties of chips sampled from the chipping treatment by harvest type and treatment in three studies of a small chipper added to a tree-length harvesting system.

Treatment	**MC**	**C**	**N**	**P**	**K**	**HHV**
			Percent			BTU/lb
2006 Clearcut						
B –Tops and Limbs	49.0	51.4	0.178	0.0144	0.0475	8235
C - Tops/limbs/understory	41.8	50.7	0.209	0.0217	0.0635	8219
2007 Thinning						
B –Tops and Limbs	43.4	54.4	0.22	0.0008	0.0007	8800
C - Tops/limbs/understory	37.7	48.4	0.38	0.0019	0.0012	8082

Site Preparation Impacts

Site preparation impacts were only evaluated for the 2006 clearcut study. Raking costs during site preparation were significantly lower in Treatment C (*alpha*=0.05) compared to Treatments A and B when understory was removed and chipped in addition to limbs and tops of merchantable trees (Table 4). Study blocks in Treatment C cost on average $39.38 per acre to rake compared to $60.53 per acre and $63.57 per acre for Treatments A and B, respectively. There was no statistically significant difference between the raking costs on Treatment A and Treatment B.

Both chipping treatments (B&C) resulted in significantly less area lost to debris piles than the roundwood only treatment (A). Treatment A averaged 1.7% of the total area compared to 1.1% with Treatment B and 1.0% with Treatment C. Treatment A was significantly greater than

Treatment B and Treatment C at the 10% level, but not at the 5% for area index. The volume index was significantly smaller for Treatment C where the understory was chipped in addition to limbs and tops. For volume index Treatment A and Treatment B were significantly higher than Treatment C at the 10% level. At the 5%, level Treatment C was significantly less than Treatment A but neither A or C were significantly different from Treatment B.

Table 4. Slash pile area and volume index estimates post harvest by blocks and treatments.

Treatment	**Piles**	**Block Area**	**Site Prep Rake Cost**	**Length**	**Width**	**Height**	**Pile Area Per Block**
	n	acres	$/acre	Averages in feet			%
A-Conventional logging							
Block 3	14	22.63	$62.97	39.3	38.0	6.7	1.8
Block 9	14	23.85	$58.18	33.7	39.2	7.0	1.6
Block 10	12	19.85	$60.45	38.8	37.3	9.5	1.7
Average	**13.3**	**22.1**	**$60.53Aa**	**37.3**	**38.2**	**7.7**	**1.7**
B-Tops/limbs							
Block 2	15	23.92	$56.44	27.0	27.8	8.2	0.9
Block 4	10	21.93	$66.69	34.6	36.1	13.6	1.1
Block 7	12	19.98	$67.57	33.3	39.8	10.8	1.5
Average	**12.3**	**21.9**	**$63.57Aa**	**31.6**	**34.6**	**10.9**	**1.1**
C-Tops/limbs/understory							
Block 1	6	21.68	$27.68	28.5	32.8	9.7	0.5
Block 5	18	25.02	$56.95	30.3	32.7	5.8	1.4
Block 8	18	24.63	$33.50	25.5	27.3	5.6	1.0
Average	**14.0**	**23.8**	**$39.38Bb**	**28.1**	**30.9**	**7.0**	**1.0**

Means with the same letter are not significantly different at the alpha=10% (upper-case letters) or 5% (lower-case letters) level.

DISCUSSION

We did not detect a significant difference in per acre roundwood production between treatments in any of the three studies. Hourly roundwood production (tons/smh) did vary significantly between treatments by study. The clearcut studies involved varying amounts of biomass removals (3.8 and 16.8 tons per acre) and the chippers easily handled this volume. Chipping did not influence hourly roundwood production in the clearcut studies. Under these conditions (clearcut harvest with less than 12 tons per acre of biomass), it appears that a small chipper can obtain additional biomass chip production without adversely impacting roundwood production.

The thinning study also showed that chipping limbs and top residue (3 green tons/acre) could be performed with no loss of roundwood production. However, when the 17 green tons per acre of understory stems were also harvested, this caused hourly roundwood production to be cut in half. Lower amounts of understory, perhaps as much as 12 green tons per acre, may be adequately handled in a thinning without serious roundwood production losses.

Chip production per smh varied by treatment in each study. All three studies experienced increased chip productivity during Treatment C as compared to Treatment B. Treatment C can greatly increase the amounts of chips produced, but can also significantly reduce roundwood production as experienced in the 2007 thinning. Harvest type and understory biomass estimates are important factors for biomass utilization considerations.

The models developed tested the sensitivity of production and cost to varying harvesting factors. The hourly production and onboard cost of both roundwood and chips were used to determine how these factors influenced cost. Treatment C was a cost effective way of utilizing understory biomass and logging residues. However, when ratios were too low (less than 3:1) roundwood production was negatively impacted and when ratios were too high (greater than 12:1) chip costs were high. Production did not suffer and cost remained competitive when roundwood to chip ratios were between 5:1 and 10:1.

Understory biomass also had both a positive and negative effect on production and cost. In Treatment C, as the amount of understory increased, chip production increased and roundwood production decreased. Chip onboard cost decreased rapidly as understory biomass increased, but cost stabilized at understory biomass levels of about 12 tons per acre.

There appeared to be a minimum total roundwood availability in tons per acre. When a treatment had less than 45 total tons available per acre the model predicted decreased roundwood and chip productivity and increased cost. Productivity and cost for both roundwood and chips appeared stable when at least 45 tons per acre were available.

Skid distance influenced both production and cost on each treatment. Roundwood production losses were experienced when skid distance exceeded 400 feet. Chip production losses were experienced when skid distances exceeded 600 feet. Treatment C was the most cost effective system over all skid distances.

When chip loading time was greater than 45 minutes per load, all treatments experienced decreased production of both roundwood and chips. Production cost as predicted from the models was the lowest for Treatment C followed by Treatment A and Treatment B. Treatment C used a joint cost approach which proportionally distributed the fixed cost of harvesting (felling, skidding, and processing) between the roundwood and chip products. Treatment C also had a lower chip production cost than Treatment B.

Fuel cost did not influence production for roundwood or chips, but it had a major impact on cost per ton. Fuel price increased roundwood onboard cost in Treatment B ($0.60/ton) and Treatment C ($0.73/ton) for every $1.00 increase in fuel cost. Increasing fuel cost again had a linear affect on chip onboard cost per ton for both treatments. Chip onboard cost increased $0.40 per ton for Treatment B and $0.33 per ton for Treatment C for every $1.00 increase in fuel cost.

The 2007 clearcut utilized a minimal delimbing approach (Treatment D) that increased hourly chip production, but sacrificed some pulpwood tops. For each ton of tops sacrificed Treatment D produced 2.1 tons of biomass chips. This minimal delimbing approach also produced 25% more roundwood per smh and used 30% less fuel. As markets for biomass develop, such modifications to product sorting will continue to evolve.

The chips produced from these biomass sources worked well in the electricity co-generation plant where they were burned and our lab analyses suggest that the chips also have very competitive heating values. The chips worked well in the live bottom trailers and provided fully loaded trailers when hauled to the mill. The easily handled chips could be loaded, hauled, and unloaded at any facility that aims to use a biomass feedstock.

Adding the chipper significantly decreased the area occupied in slash after the harvest, thus providing more area that can be planted. In the flatwoods, raking is necessary for artificial regeneration and the raking cost was significantly lower when additional understory stems were removed along with the limbs and tops. Both Treatments B and Treatments C were favorable for reducing slash from the site, but Treatment C also had significant site preparation cost savings.

Nutrient removal is a major concern when additional material is removed from a harvest site. However, the volumes we removed during our studies did not appear significant enough to promote concern. Future studies should monitor the site to see if our relatively low nutrient removals have a lasting effect on long-term site productivity.

Chipping limbs and tops alone removed relatively small amounts of N, P, and K from the site – an amount roughly equivalent to annual atmospheric deposition. When small understory trees were also chipped, nutrients removals increased by a factor of 4-5, reflecting both the higher tonnages removed and the different nature of the material. On sites where nutrient availability is a concern, harvesting small understory tress may not be desirable. It is also important to note that while raking did not remove nutrients, it did concentrate them into piles. As a result, most of the site may experience the same nutrient "loss" on a micro-site basis with both chipping and tree-length systems.

CONCLUSION

Forest biomass recovery by adding a small chipper to a tree-length harvesting system in planted pines stands across the southern United States appears to be the most feasible in clearcut harvest operations. Clearcuts are better than thinnings for biomass utilization primarily because roundwood production is not already challenged by the small tree size and tight operating space associated with thinnings. The best suited clearcut operations appear to be stands that have at least 45 total available tons per acre of roundwood and standing understory level of 12 tons per acre or more. Treatment C was our overall best method for harvesting biomass. Market prices will largely impact how product allocation between roundwood and chips is dictated and how cost and productivity will be affected. Biomass chipping in clearcuts was most attractive at roundwood to chip ratios between 5 and 10; a higher ratio did not utilize the chipper enough while a lower ratio reduced roundwood production.

Our sensitivity analysis focused on onboard costs for roundwood and chips, but trucking is also an important cost associated with the removal of biomass. For all three models we used a $0.12/ton-mile cost of transporting products and a haul distance of 40 miles. As haul cost per ton-mile and distance increase, so too will the delivered cost of products (Figure 20). With increased trucking fuel prices and trucking haul distance the overall cost per ton of biomass will increase. Distance between the woods and the market should be considered when contemplating biomass recovery. Overall increasing interest in biomass utilization will dictate market prices and locations.

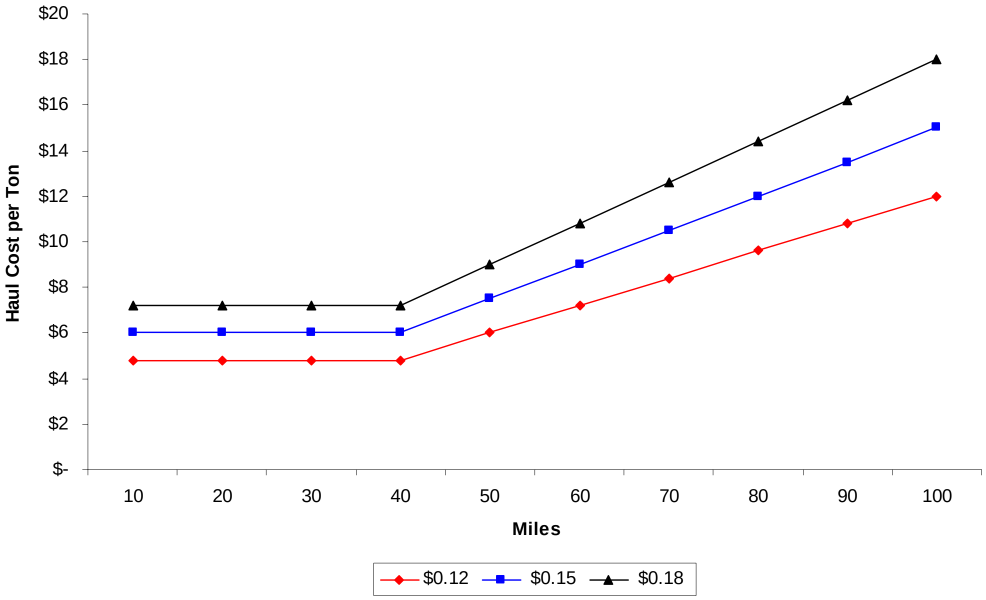

Figure 20. Haul cost per ton increase or decrease depending on $/ton-mile and haul distance.

As the value of biomass chips increase, so will the direct and indirect benefits that go to the landowners. Biomass utilization could provide a direct revenue source to the landowner when sold as an additional product, but it could also provide an indirect benefit in its ability to clean up a harvest site when removed. The cleaner harvest site can significantly reduce site preparation cost. Additional the harvest of this material can increase the area that is available for regeneration and subsequent forest growth. Biomass removal can further have indirect benefits by increasing the aesthetic value of an area after harvest.

CHAPTER 3

SUMMARY AND CONCLUSIONS

SUMMARY

We did not detect a significant difference in per acre roundwood production between treatments in any of the three studies. Hourly roundwood production (tons/smh) did vary significantly between treatments by study. The clearcut studies involved varying amounts of biomass removals (3.8 and 16.8 tons per acre) and the chippers easily handled this volume. Chipping did not influence hourly roundwood production in the clearcut studies. Under these conditions (clearcut harvest with less than 12 tons per acre of biomass), it appears that a small chipper can obtain additional biomass chip production without adversely impacting roundwood production.

The thinning study also showed that chipping limbs and top residue (3 green tons/acre) could be performed with no loss of roundwood production. However, when the 17 green tons per acre of understory stems were also harvested, this caused hourly roundwood production to be cut in half. Lower amounts of understory, perhaps as much as 12 green tons per acre, may be adequately handled in a thinning without serious roundwood production losses.

Chip production per smh varied by treatment in each study. All three studies experienced increased chip productivity during Treatment C as compared to Treatment B. Treatment C can greatly increase the amounts of chips produced, but can also significantly reduce roundwood production as experienced in the 2007 thinning. Harvest type and understory biomass estimates are important factors for biomass utilization considerations.

The models developed tested the sensitivity of production and cost to varying harvesting factors. The hourly production and onboard cost of both roundwood and chips were used to determine how these factors influenced cost. Treatment C was a cost effective way of utilizing understory biomass and logging residues. However, when ratios were too low (less than 3:1) roundwood production was negatively impacted and when ratios were too high (greater than 12:1) chip costs were high. Production did not suffer and cost remained competitive when roundwood to chip ratios were between 5:1 and 10:1.

Understory biomass also had both a positive and negative effect on production and cost. In Treatment C, as the amount of understory increased, chip production increased and roundwood production decreased. Chip onboard cost decreased rapidly as understory biomass increased, but cost stabilized at understory biomass levels of about 12 tons per acre.

There appeared to be a minimum total roundwood availability in tons per acre. When a treatment had less than 45 total tons available per acre the model predicted decreased roundwood and chip productivity and increased cost. Productivity and cost for both roundwood and chips appeared stable when at least 45 tons per acre were available.

Skid distance influenced both production and cost on each treatment. Roundwood production losses were experienced when skid distance exceeded 400 feet. Chip production losses were experienced when skid distances exceeded 600 feet. Treatment C was the most cost effective system over all skid distances.

When chip loading time was greater than 45 minutes per load, all treatments experienced decreased production of both roundwood and chips. Production cost as predicted from the models was the lowest for Treatment C followed by Treatment A and Treatment B. Treatment C used a joint cost approach which proportionally distributed the fixed cost of harvesting (felling, skidding, and processing) between the roundwood and chip products. Treatment C also had a lower chip production cost than Treatment B.

Fuel cost did not influence production for roundwood or chips, but it had a major impact on cost per ton. Fuel price increased roundwood onboard cost in Treatment B ($0.60/ton) and Treatment C ($0.73/ton) for every $1.00 increase in fuel cost. Increasing fuel cost again had a linear affect on chip onboard cost per ton for both treatments. Chip onboard cost increased $0.40 per ton for Treatment B and $0.33 per ton for Treatment C for every $1.00 increase in fuel cost.

The 2007 clearcut utilized a minimal delimbing approach (Treatment D) that increased hourly chip production, but sacrificed some pulpwood tops. For each ton of tops sacrificed Treatment D produced 2.1 tons of biomass chips. This minimal delimbing approach also produced 25% more roundwood per smh and used 30% less fuel. As markets for biomass develop, such modifications to product sorting will continue to evolve.

The chips produced from these biomass sources worked well in the electricity co-generation plant where they were burned and our lab analyses suggest that the chips also have very competitive heating values. The chips worked well in the live bottom trailers and provided fully loaded trailers when hauled to the mill. The easily handled chips could be loaded, hauled, and unloaded at any facility that aims to use a biomass feedstock.

Adding the chipper significantly decreased the area occupied in slash after the harvest, thus providing more area that can be planted. In the flatwoods, raking is necessary for artificial regeneration and the raking cost was significantly lower when additional understory stems were removed along with the limbs and tops. Both Treatments B and Treatments C were favorable for reducing slash from the site, but Treatment C also had significant site preparation cost savings.

Nutrient removal is a major concern when additional material is removed from a harvest site. However, the volumes we removed during our studies did not appear significant enough to promote concern. Future studies should monitor the site to see if our relatively low nutrient removals have a lasting effect on long-term site productivity.

Chipping limbs and tops alone removed relatively small amounts of N, P, and K from the site – an amount roughly equivalent to annual atmospheric deposition. When small understory trees were also chipped, nutrients removals increased by a factor of 4-5, reflecting both the higher tonnages removed and the different nature of the material. On sites where nutrient availability is a concern, harvesting small understory tress may not be desirable. It is also important to note that while raking did not remove nutrients, it did concentrate them into piles. As a result, most of the site may experience the same nutrient “loss” on a micro-site basis with both chipping and tree-length systems.

CONCLUSION

Forest biomass recovery by adding a small chipper to a tree-length harvesting system in planted pines stands across the southern United States appears to be the most feasible in clearcut harvest operations. Clearcuts are better than thinnings for biomass utilization primarily because roundwood production is not already challenged by the small tree size and tight operating space associated with thinnings. The best suited clearcut operations appear to be stands that have at least 45 total available tons per acre of roundwood and standing understory level of 12 tons per acre or more. Treatment C was our overall best method for harvesting biomass. Market prices will largely impact how product allocation between roundwood and chips is dictated and how cost and productivity will be affected. Biomass chipping in clearcuts was most attractive at roundwood to chip ratios between 5 and 10; a higher ratio did not utilize the chipper enough while a lower ratio reduced roundwood production.

Our sensitivity analysis focused on onboard costs for roundwood and chips, but trucking is also an important cost associated with the removal of biomass. For all three models we used a \$0.12/ton-mile cost of transporting products and a haul distance of 40 miles. As haul cost per ton-mile and distance increase, so too will the delivered cost of products. With increased trucking fuel prices and trucking haul distance the overall cost per ton of biomass will increase. Distance between the woods and the market should be considered when contemplating biomass recovery.   Overall increasing interest in biomass utilization will dictate market prices and locations.

As the value of biomass chips increase, so will the direct and indirect benefits that go to the landowners. Biomass utilization could provide a direct revenue source to the landowner when sold as an additional product, but it could also provide an indirect benefit in its ability to clean up a harvest site when removed. The cleaner harvest site can significantly reduce site preparation cost. Additional the harvest of this material can increase the area that is available for regeneration and subsequent forest growth. Biomass removal can further have indirect benefits by increasing the aesthetic value of an area after harvest.

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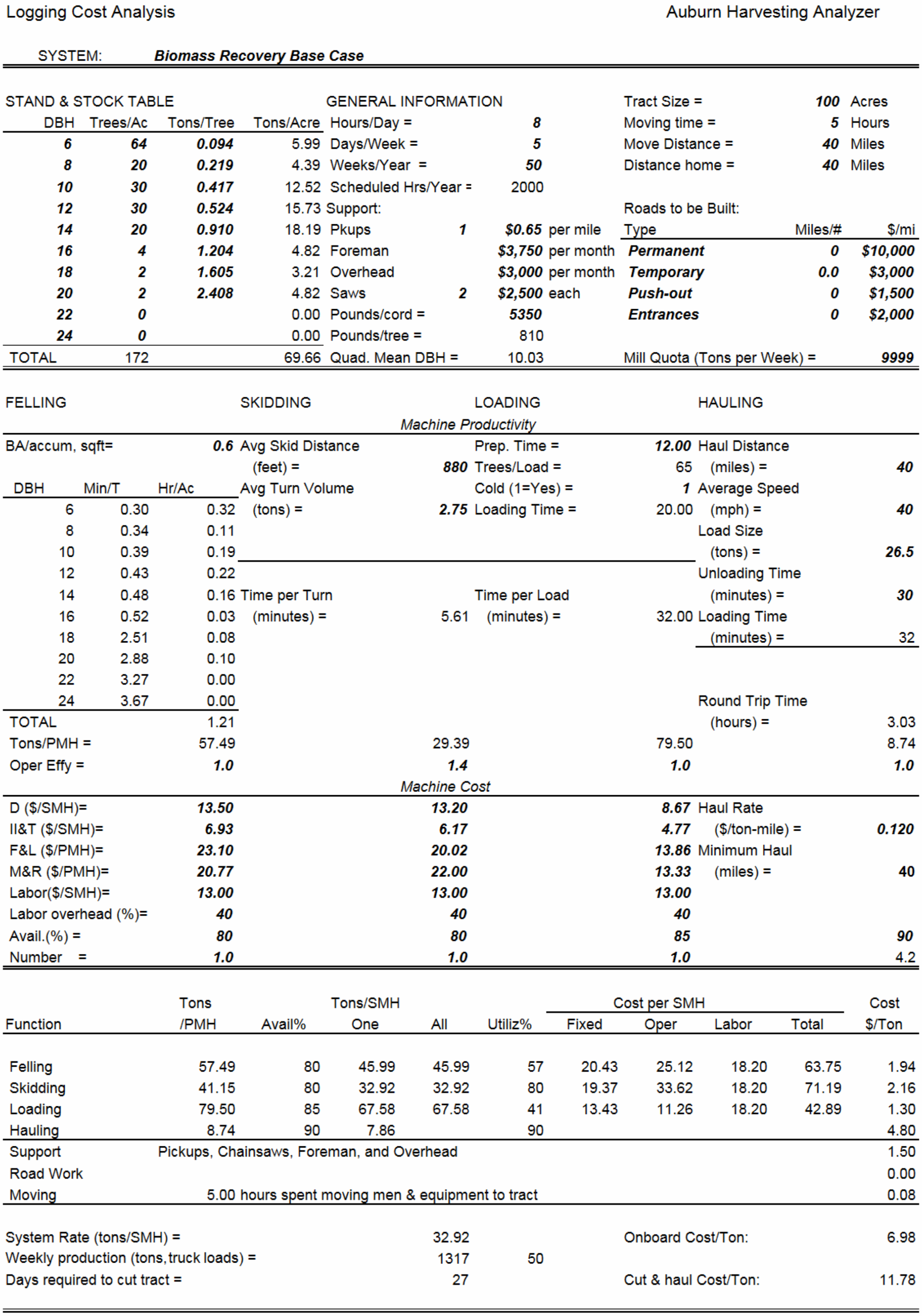
APPENDICES

Appendix A. Base Case Sensitivity Model



Logging Cost Analysis | Auburn Harvesting Analyzer

SYSTEM: ***Biomass Recovery Base Case***

STAND & STOCK TABLE

DBH	Trees/Ac	Tons/Tree	Tons/Acre
6	***64***	***0.094***	5.99
8	***20***	***0.219***	4.39
10	***30***	***0.417***	12.52
12	***30***	***0.524***	15.73
14	***20***	***0.910***	18.19
16	***4***	***1.204***	4.82
18	***2***	***1.605***	3.21
20	***2***	***2.408***	4.82
22	***0***		0.00
24	***0***		0.00
TOTAL	172		69.66

GENERAL INFORMATION

Hours/Day =		***8***	
Days/Week =		***5***	
Weeks/Year =		***50***	
Scheduled Hrs/Year =		2000	
Support:			
Pkups	***1***	***$0.65***	per mile
Foreman		***$3,750***	per month
Overhead		***$3,000***	per month
Saws	***2***	***$2,500***	each
Pounds/cord =		***5350***	
Pounds/tree =		810	
Quad. Mean DBH =		10.03	

Tract Size =	***100***	Acres
Moving time =	***5***	Hours
Move Distance =	***40***	Miles
Distance home =	***40***	Miles

Roads to be Built:

Type	Miles/#	$/mi
Permanent	***0***	***$10,000***
Temporary	***0.0***	***$3,000***
Push-out	***0***	***$1,500***
Entrances	***0***	***$2,000***

Mill Quota (Tons per Week) = ***9999***

Machine Productivity

FELLING

BA/accum, sqft= ***0.6***

DBH	Min/T	Hr/Ac
6	0.30	0.32
8	0.34	0.11
10	0.39	0.19
12	0.43	0.22
14	0.48	0.16
16	0.52	0.03
18	2.51	0.08
20	2.88	0.10
22	3.27	0.00
24	3.67	0.00
TOTAL		1.21

SKIDDING

Avg Skid Distance (feet) = ***880***

Avg Turn Volume (tons) = ***2.75***

Time per Turn (minutes) = 5.61

LOADING

Prep. Time = ***12.00***

Trees/Load = 65

Cold (1=Yes) = ***1***

Loading Time = 20.00

Time per Load (minutes) = 32.00

HAULING

Haul Distance (miles) = ***40***

Average Speed (mph) = ***40***

Load Size (tons) = ***26.5***

Unloading Time (minutes) = ***30***

Loading Time (minutes) = 32

Round Trip Time (hours) = 3.03

	FELLING	SKIDDING	LOADING	HAULING
Tons/PMH =	57.49	29.39	79.50	8.74
Oper Effy =	***1.0***	***1.4***	***1.0***	***1.0***

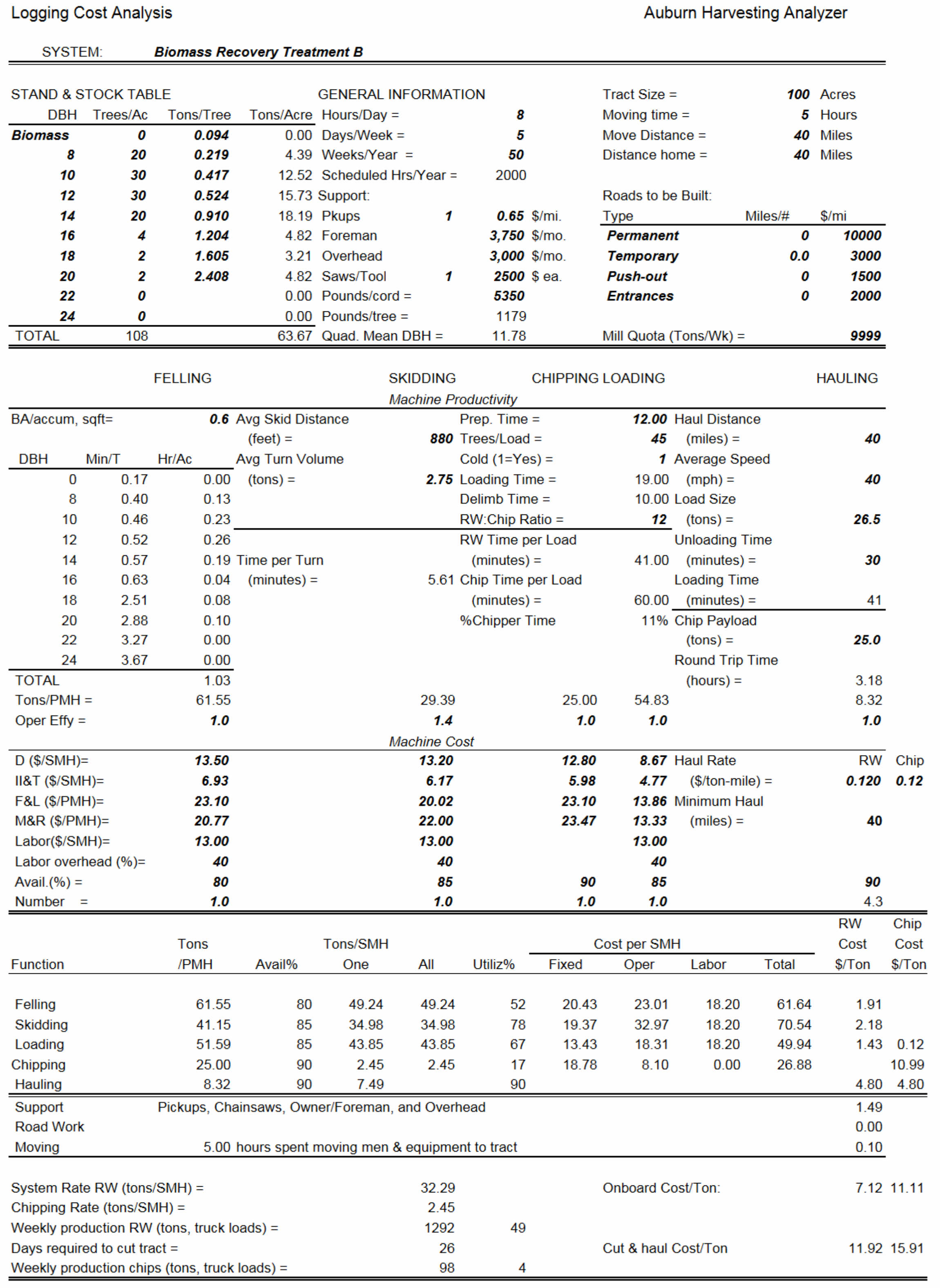
Machine Cost

	FELLING	SKIDDING	LOADING	HAULING
D ($/SMH)=	***13.50***	***13.20***	***8.67***	Haul Rate
II&T ($/SMH)=	***6.93***	***6.17***	***4.77***	($/ton-mile) = ***0.120***
F&L ($/PMH)=	***23.10***	***20.02***	***13.86***	Minimum Haul
M&R ($/PMH)=	***20.77***	***22.00***	***13.33***	(miles) = ***40***
Labor($/SMH)=	***13.00***	***13.00***	***13.00***	
Labor overhead (%)=	***40***	***40***	***40***	
Avail.(%) =	***80***	***80***	***85***	***90***
Number =	***1.0***	***1.0***	***1.0***	4.2

Function	Tons /PMH	Avail%	Tons/SMH One	Tons/SMH All	Utiliz%	Cost per SMH Fixed	Cost per SMH Oper	Cost per SMH Labor	Cost per SMH Total	Cost $/Ton
Felling	57.49	80	45.99	45.99	57	20.43	25.12	18.20	63.75	1.94
Skidding	41.15	80	32.92	32.92	80	19.37	33.62	18.20	71.19	2.16
Loading	79.50	85	67.58	67.58	41	13.43	11.26	18.20	42.89	1.30
Hauling	8.74	90	7.86		90					4.80
Support	Pickups, Chainsaws, Foreman, and Overhead									1.50
Road Work										0.00
Moving	5.00 hours spent moving men & equipment to tract									0.08

System Rate (tons/SMH) =	32.92		Onboard Cost/Ton:	6.98
Weekly production (tons,truck loads) =	1317	50		
Days required to cut tract =	27		Cut & haul Cost/Ton:	11.78

Appendix B. Treatment B Sensitivity Model



Logging Cost Analysis

Auburn Harvesting Analyzer

SYSTEM: ***Biomass Recovery Treatment B***

STAND & STOCK TABLE

DBH	Trees/Ac	Tons/Tree	Tons/Acre
Biomass	***0***	***0.094***	0.00
8	***20***	***0.219***	4.39
10	***30***	***0.417***	12.52
12	***30***	***0.524***	15.73
14	***20***	***0.910***	18.19
16	***4***	***1.204***	4.82
18	***2***	***1.605***	3.21
20	***2***	***2.408***	4.82
22	***0***		0.00
24	***0***		0.00
TOTAL	108		63.67

GENERAL INFORMATION

Hours/Day =		***8***	
Days/Week =		***5***	
Weeks/Year =		***50***	
Scheduled Hrs/Year =		2000	
Support:			
Pkups	***1***	***0.65***	$/mi.
Foreman		***3,750***	$/mo.
Overhead		***3,000***	$/mo.
Saws/Tool	***1***	***2500***	$ ea.
Pounds/cord =		***5350***	
Pounds/tree =		1179	
Quad. Mean DBH =		11.78	

Tract Size =	***100***	Acres
Moving time =	***5***	Hours
Move Distance =	***40***	Miles
Distance home =	***40***	Miles

Roads to be Built:

Type	Miles/#	$/mi
Permanent	***0***	***10000***
Temporary	***0.0***	***3000***
Push-out	***0***	***1500***
Entrances	***0***	***2000***

Mill Quota (Tons/Wk) = ***9999***

		FELLING		SKIDDING		CHIPPING	LOADING		HAULING	
				Machine Productivity						
BA/accum, sqft=		***0.6***	Avg Skid Distance		Prep. Time =		***12.00***	Haul Distance		
			(feet) =	***880***	Trees/Load =		***45***	(miles) =	***40***	
DBH	Min/T	Hr/Ac	Avg Turn Volume		Cold (1=Yes) =		***1***	Average Speed		
0	0.17	0.00	(tons) =	***2.75***	Loading Time =		19.00	(mph) =	***40***	
8	0.40	0.13			Delimb Time =		10.00	Load Size		
10	0.46	0.23			RW:Chip Ratio =		***12***	(tons) =	***26.5***	
12	0.52	0.26			RW Time per Load			Unloading Time		
14	0.57	0.19	Time per Turn		(minutes) =		41.00	(minutes) =	***30***	
16	0.63	0.04	(minutes) =	5.61	Chip Time per Load			Loading Time		
18	2.51	0.08			(minutes) =		60.00	(minutes) =	41	
20	2.88	0.10			%Chipper Time		11%	Chip Payload		
22	3.27	0.00						(tons) =	***25.0***	
24	3.67	0.00						Round Trip Time		
TOTAL		1.03						(hours) =	3.18	
Tons/PMH =		61.55		29.39		25.00	54.83		8.32	
Oper Effy =		***1.0***		***1.4***		***1.0***	***1.0***		***1.0***	
				Machine Cost						
D ($/SMH)=		***13.50***		***13.20***		***12.80***	***8.67***	Haul Rate	RW	Chip
II&T ($/SMH)=		***6.93***		***6.17***		***5.98***	***4.77***	($/ton-mile) =	***0.120***	***0.12***
F&L ($/PMH)=		***23.10***		***20.02***		***23.10***	***13.86***	Minimum Haul		
M&R ($/PMH)=		***20.77***		***22.00***		***23.47***	***13.33***	(miles) =	***40***	
Labor($/SMH)=		***13.00***		***13.00***			***13.00***			
Labor overhead (%)=		***40***		***40***			***40***			
Avail.(%) =		***80***		***85***		***90***	***85***		***90***	
Number =		***1.0***		***1.0***		***1.0***	***1.0***		4.3	

	Tons		Tons/SMH			Cost per SMH				RW Cost	Chip Cost
Function	/PMH	Avail%	One	All	Utiliz%	Fixed	Oper	Labor	Total	$/Ton	$/Ton
Felling	61.55	80	49.24	49.24	52	20.43	23.01	18.20	61.64	1.91	
Skidding	41.15	85	34.98	34.98	78	19.37	32.97	18.20	70.54	2.18	
Loading	51.59	85	43.85	43.85	67	13.43	18.31	18.20	49.94	1.43	0.12
Chipping	25.00	90	2.45	2.45	17	18.78	8.10	0.00	26.88		10.99
Hauling	8.32	90	7.49		90					4.80	4.80
Support	Pickups, Chainsaws, Owner/Foreman, and Overhead									1.49	
Road Work										0.00	
Moving	5.00 hours spent moving men & equipment to tract									0.10	

System Rate RW (tons/SMH) =	32.29		Onboard Cost/Ton:	7.12	11.11
Chipping Rate (tons/SMH) =	2.45				
Weekly production RW (tons, truck loads) =	1292	49			
Days required to cut tract =	26		Cut & haul Cost/Ton	11.92	15.91
Weekly production chips (tons, truck loads) =	98	4			

Appendix C. Treatment C Sensitivity Model

Logging Cost Analysis

Auburn Harvesting Analyzer

SYSTEM: ***Biomass Recover Treatment C***

STAND & STOCK TABLE

DBH	Trees/Ac	Tons/Tree	Tons/Acre
Biomass	***0***	***0.094***	12.73
8	***20***	***0.219***	4.39
10	***30***	***0.417***	12.52
12	***30***	***0.524***	15.73
14	***20***	***0.910***	18.19
16	***4***	***1.204***	4.82
18	***2***	***1.605***	3.21
20	***2***	***2.408***	4.82
22	***0***		0.00
24	***0***		0.00
TOTAL	108		63.67

GENERAL INFORMATION

Hours/Day = ***8***
Days/Week = ***5***
Weeks/Year = ***50***
Scheduled Hrs/Year = 2000

Support:

Pkups	***1***	***0.65***	$/mi.
Foreman		***3,750***	$/mo.
Overhead		***3,000***	$/mo.
Saws/Tool	***1***	***2500***	$ ea.

Pounds/cord = ***5350***
Pounds/tree = 1179
Quad. Mean DBH = 11.78

Tract Size = ***100*** Acres
Moving time = ***5*** Hours
Move Distance = ***40*** Miles
Distance home = ***40*** Miles

Roads to be Built:

Type	Miles/#	$/mi
Permanent	***0***	***10000***
Temporary	***0.0***	***3000***
Push-out	***0***	***1500***
Entrances	***0***	***2000***

Mill Quota (Tons/Wk) = ***9999***

FELLING | SKIDDING | CHIPPING LOADING | HAULING

Machine Productivity

FELLING

BA/accum, sqft= ***0.6***

DBH	Min/T	Hr/Ac
0	0.17	0.00
8	0.40	0.13
10	0.46	0.23
12	0.52	0.26
14	0.57	0.19
16	0.63	0.04
18	2.51	0.08
20	2.88	0.10
22	3.27	0.00
24	3.67	0.00
TOTAL		1.03

SKIDDING

Avg Skid Distance (feet) = ***880***
Avg Turn Volume (tons) = ***2.75***
Time per Turn (minutes) = 5.61

CHIPPING LOADING

Prep. Time = ***12.00***
Trees/Load = ***45***
Cold (1=Yes) = ***1***
Loading Time = 19.00
Delimb Time = 10.00
RW:Chip Ratio = ***5***
RW Time per Load (minutes) = 41.00
Chip Time per Load (minutes) = 60.00
%Chipper Time 23%

HAULING

Haul Distance (miles) = ***40***
Average Speed (mph) = ***40***
Load Size (tons) = ***26.5***
Unloading Time (minutes) = ***30***
Loading Time (minutes) = 41
Chip Payload (tons) = ***25.0***
Round Trip Time (hours) = 3.18

	Felling	Skidding	Chipping	Loading	Hauling
Tons/PMH =	61.55	29.39	25.00	54.83	8.32
Oper Effy =	***1.0***	***1.4***	***1.0***	***1.0***	***1.0***

Machine Cost

	Felling	Skidding	Chipping	Loading	Hauling
D ($/SMH)=	***13.50***	***13.20***	***12.80***	***8.67***	
II&T ($/SMH)=	***6.93***	***6.17***	***5.98***	***4.77***	
F&L ($/PMH)=	***23.10***	***20.02***	***23.10***	***13.86***	
M&R ($/PMH)=	***20.77***	***22.00***	***23.47***	***13.33***	
Labor($/SMH)=	***13.00***	***13.00***		***13.00***	
Labor overhead (%)=	***40***	***40***		***40***	
Avail.(%) =	***80***	***90***	***85***	***85***	***90***
Number =	***1.0***	***1.0***	***1.0***	***1.0***	4.1

Haul Rate	RW	Chip
($/ton-mile) =	***0.120***	***0.12***

Minimum Haul (miles) = ***40***

Function	Tons /PMH	Avail%	Tons/SMH One	Tons/SMH All	Utiliz%	Cost per SMH Fixed	Cost per SMH Oper	Cost per SMH Labor	Cost per SMH Total	RW Cost $/Ton	Chip Cost $/Ton
Felling	61.55	80	49.24	49.24	58	20.43	25.43	18.20	64.06	1.50	0.30
Skidding	41.15	90	37.04	37.04	87	19.37	36.43	18.20	74.00	1.73	0.35
Loading	54.83	85	36.05	36.05	65	13.43	17.69	18.20	49.33	1.15	0.23
Chipping	25.00	85	4.81	4.81	39	18.78	18.28	0.00	37.06		7.70
Hauling	8.32	90	7.49		90					4.80	4.80
Support	Pickups, Chainsaws, Foreman, and Overhead									1.35	
Road Work										0.00	
Moving	5.00 hours spent moving men & equipment to tract									0.10	

Predicted System Rate RW = 20.86
System Rate RW (tons/SMH) = 30.86
Chipping Rate (tons/SMH) = 4.81
Weekly production RW (tons, truck loads) = 1235 47
Days required to cut tract = 27
Weekly production chips (tons, truck loads) = 192 7

Onboard Cost/Ton: 5.83 10.03
Cut & haul Cost/Ton 10.63 14.83

Appendix D. Machine Rate Assumptions Used During Sensitivity Testing

Machine Rate Assumptions:

Interest	8%	Labor	$13.00
Insurance	1%	Fringe	40%
Taxes	2%	Fuel	$2.75

Machine: Feller-Buncher

Purchase Price	$180,000	Fuel	6	gal/PMH @
Salvage Value	25%	Lube	40	% Fuel
Economic Life (yr)	5	Maint. & Repair		100%
Utilization	65%			

Machine: Skidder

Purchase Price	$165,000	Fuel	5.2	gal/PMH @
Salvage Value	20%	Lube	40	% Fuel
Economic Life (yr)	5	Maint. & Repair		100%
Utilization	60%			

Machine: Loader

Purchase Price	$130,000	Fuel	3.6	gal/PMH @
Salvage Value	20%	Lube	40	% Fuel
Economic Life (yr)	6	Maint. & Repair		100%
Utilization	65%			

Machine: Chipper

Purchase Price	$160,000	Fuel	6	gal/PMH @
Salvage Value	20%	Lube	40	% Fuel
Economic Life (yr)	5	Maint. & Repair		110%
Utilization	60%			

Appendix E. Summary of data collected by treatment and by block for the 2006 clearcut study.

Treatment	**Loads**	**Tons**	**Days**	**SMH**	**Acres**	**Tons /load**	**Tons /day**	**Tons /acre**	**Loads /day**	**Loads/ acre**	**Round Wood Tons/Acre**	**Chip Tons /Acre**	**Tons/ SMH**	**Fuel Use Gallon/Ton**
A - Conventional Harvest														
Block 3	68	1785	6	52.2	22.63	26.2	297.5	78.9	11	3	78.9	--	34.2	0.4
Block 9	46	1406	7	59.0	23.85	30.6	200.9	59.0	7	2	59.0	--	23.8	0.5
Block 10	43	1279	5	42.5	19.85	29.8	255.9	64.4	9	2	64.4	--	30.1	0.4
Totals	157	4470	18	153.7	66.33	86.6	754.2	202.3	27	7	202.3	--	88.1	1.3
Average	**52**	**1490**	**6**	**51.2**	**22.11**	**28.9**	**251.4**	**67.4**	**9**	**2**	**67.4 Aa**	**--**	**29.4 Aa**	**0.4 Aa**
B -Tops and Limbs														
Block 2	66	1699	8	62.2	23.92	25.7	212.4	71.0	8	3	70.0	1.0	27.3	0.8
Block 4	58	1448	8	60.7	21.93	25.0	180.9	66.0	7	3	62.4	3.7	23.8	0.9
Block 7	60	1637	7	61.0	19.98	27.3	233.9	81.9	9	3	75.3	6.6	26.8	0.8
Totals	184	4784	23	184.0	65.83	78.0	627.2	219.0	24	8	207.7	11.3	78.0	2.5
Average	**61**	**1595**	**7.7**	**61.3**	**21.94**	**26.0**	**209.1**	**73.0**	**8**	**3**	**69.2 Aa**	**3.8 Aa**	**26.0 Aa**	**0.8 Bb**
C - Tops, Limbs, & Understory														
Block 1	63	1698	7	50.5	21.68	26.9	242.5	78.3	9	3	71.1	7.2	33.6	0.9
Block 5	77	2052	10	78.7	25.02	26.6	205.2	82.0	8	3	68.1	13.9	26.1	0.8
Block 8	49	1333	6	42.5	24.63	27.2	222.2	54.1	8	2	42.9	11.3	31.4	0.8
Totals	189	5083	23	171.7	71.33	80.8	669.9	214.4	25	8	182.0	32.4	91.0	2.5
Average	**63**	**1694**	**7.7**	**57.2**	**23.78**	**26.9**	**223.3**	**71.5**	**8**	**3**	**60.7 Aa**	**10.8 Ba**	**30.3 Aa**	**0.8 Bb**

Means with the same letter are not significantly different at the alpha 5% level.

Appendix F. Summary of data collected by treatment and by block for the 2007 thinning study.

Treatment	Loads	Tons	Days	SMH	Acres	Tons/ load	Tons/ day	Tons/ acre	Loads/ day	Loads/ acre	Round Wood Tons/Acre	Chip Tons/Acre	Roundwood Tons/SMH	Tons/ SMH	Fuel Use Gallon/ Ton
B - Top[s and Limbs															
Block 1	13	325	3	21.0	13.86	25.0	130	23.4	5	1	20.50	2.95	13.53	15.48	0.5
Block 4	10	254	1	9.0	11.63	25.4	254	21.8	10	1	19.59	2.25	25.31	28.23	0.6
Block 6	21	536	2	17.5	18.92	25.5	268	28.3	11	1	24.20	4.13	26.16	30.63	0.6
Totals	44	1115	6	47.5	44.41	75.9	652	73.6	26	3	64.28	9.34	65.00	74.34	1.7
Average	**15**	**372**	**2**	**15.8**	**14.80**	**25.3**	**217**	**24.5**	**9**	**1**	**21.43A**	**3.11A**	**21.67A**	**24.78A**	**0.6A**
C - Tops, Limbs, & Understory															
Block 2	19	427	3	23.0	10.47	22.5	142	40.8	6	2	21.57	19.19	9.82	18.56	1.0
Block 3	19	442	3	28.5	11.77	23.3	147	37.6	6	2	15.47	22.12	6.39	15.53	1.0
Block 5	24	625	3	23.0	12.72	26.0	250	49.1	10	2	30.16	18.96	16.68	27.17	0.7
Totals	62	1494	9	74.5	34.96	71.8	540	127.5	22	5	67.20	60.2	32.89	61.25	2.7
Average	**21**	**498**	**3**	**24.8**	**11.65**	**23.9**	**180**	**42.5**	**7**	**2**	**22.40A**	**20.0B**	**10.96B**	**20.42A**	**0.9B**

Means with the same letter are not significantly different at the alpha 5% level.

Appendix G. Summary of data collected by treatment and by block for the 2007 clearcut study.

Treatment	Loads	Tons	Days	SMH	Acres	Tons/ load	Tons/ day	Tons /acre	Loads/ day	Loads/ acre	Round Wood Tons/Acre	Chip Tons/Acre	Roundwood Tons/SMH	Total Tons/SMH	Fuel Use Gallon/Ton
A - Conventional Harvest															
Block 2	16	408.55	1	9.5	15.00	25.5	344.04	27.2	13	1	27.24	--	43.01	43.01	0.6
Blcok 5	30	781.43	2	18.0	14.50	26.0	347.3	53.9	13	2	53.89	--	43.41	43.41	0.7
Block 10	12	277.66	1	5.0	13.70	23.1	444.26	20.3	19	1	20.27	--	55.53	55.53	0.5
Totals	58	1467.6	4	32.5	43.20	74.7	1135.6	101.4	46	4	101.40		114.95	141.95	1.8
Average	**19**	**489**	**1**	**10.8**	**14.40**	**24.9**	**378.5**	**33.8**	**15**	**1**	**33.80A**		**47.32A**	**47.32AB**	**0.6A**
B - Tops and Limbs															
Block 1	29	669.18	3	22.8	16.80	23.1	234.8	39.8	10	2	36.58	3.25	26.95	29.35	0.6
Block 7	24	614.57	3	22.5	14.00	25.6	218.51	43.9	9	2	36.90	6.99	22.96	27.31	0.8
Block 9	18	412.23	1	9.0	12.50	22.9	366.43	33.0	16	1	28.60	4.38	39.73	45.80	0.7
Totals	71	1696	7	54.3	43.30	71.6	819.74	116.7	35	5	102.09	14.62	89.64	102.47	2.1
Average	**24**	**565**	**2**	**18.1**	**14.43**	**23.9**	**273.2**	**38.9**	**12**	**2**	**34.03A**	**4.87A**	**29.88B**	**34.16B**	**0.7A**
C - Tops, Limbs, & Understory															
Block 3	35	878.61	2	18.0	15.40	25.1	390.49	57.1	16	2	40.11	16.94	34.32	48.81	0.8
Block 8	43	1062.9	3	22.0	15.20	24.7	386.51	69.9	16	3	46.63	23.30	32.21	48.31	0.7
Block 11	20	496.88	1	8.0	12.30	24.8	496.88	40.4	20	2	30.32	10.07	46.62	62.11	0.5
Totals	98	2438.4	6	48.0	42.90	74.7	1273.9	167.4	51	7	117.06	50.31	113.16	159.24	2.0
Average	**33**	**813**	**2**	**16.0**	**14.30**	**24.9**	**424.6**	**55.8**	**17**	**2**	**39.02A**	**16.77B**	**37.72AB**	**53.08A**	**0.7A**
D - Intact Tops															
Block 4	32	718.53	2	15.3	14.10	22.5	376.93	51.0	17	2	39.43	11.53	36.46	47.12	0.7
Block 6	26	642.95	2	14.5	14.50	24.7	354.73	44.3	14	2	36.59	7.75	36.59	44.34	0.6
Block 12	18	454.78	1	9.5	12.30	25.3	382.97	37.0	15	1	30.19	6.78	39.09	47.87	0.6
Totals	76	1816.3	5	39.3	40.90	72.4	1114.6	132.3	46	6	106.22	26.06	112.14	139.33	1.9
Average	**25**	**605**	**2**	**13.1**	**13.63**	**24.1**	**371.5**	**44.1**	**15**	**2**	**35.41A**	**8.69AB**	**37.38AB**	**46.44AB**	**0.6A**

Means with the same letter are not significantly different at the alpha 5% level.