

Anticipated Impact of a Vibrant Wood-to-Energy Market on the
U.S. South's Wood Supply Chain

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ABSTRACT

Recent emphasis on producing energy from woody biomass has raised questions about the impact of a vibrant wood-to-energy market on the southern wood supply chain, which consists of forest landowners, forest industry mills, and harvesting contractors. This study utilized two surveys of southern wood supply chain participants and a designed operational study of an energywood harvest to investigate the impact of an expanded wood-to-energy market on each member of the southern wood supply chain. First, a survey of consulting foresters was conducted to examine how harvest tract size, forest ownership, and forest industry structure have changed within the U.S. South and how foresters expect the wood-to-energy market to impact the wood supply chain in the future. Second, this study employed a mail survey of forest landowners, forest industry mills, and wood-to-energy facilities from the thirteen southern states in order to investigate expected competition for resources, wood supply chain profitability, and landowner willingness to sell timber to energy facilities. Third, this study conducted a designed operational study on a southern pine clearcut in the Coastal Plain of North Carolina, with three replications of three harvest prescriptions to measure harvesting productivity and costs when harvesting woody biomass for energy. The three treatments were: a Conventional roundwood only harvest (control), an Integrated harvest in which roundwood was delivered to traditional mills and residuals were chipped for energy, and a Chip harvest in which all stems were chipped for energy use.

Results from the two surveys suggest that timber markets are inadequate in many areas of the South as a result of expanded timber supply and reduced forest products industry capacity. Only 12% of responding landowners and foresters had sold wood to an energy facility, indicating that wood-to-energy markets are non-existent in many areas of the South. Nonetheless, 98% of consulting foresters and 90% of landowners reported a willingness to sell timber to an energy facility if the right price were offered. Consulting foresters expected wood-to-energy facilities to provide an additional market for wood, and not displace forest products industry capacity. However, two-thirds of consulting foresters, wood-to-energy facilities, and private landowners expected competition between mills and energy facilities while 95% of fibermills (pulp/paper and composite mills) expected competition. Fibermills were much more concerned about competition for resources and increases in wood costs than any other member of the southern wood supply chain.

The operational study documented the challenges facing some harvesting contractors in economically producing energywood. Onboard truck roundwood costs increased from \$9.35 green t⁻¹ in the Conventional treatment to \$10.98 green t⁻¹ in the Integrated treatment as a result of reduced felling and skidding productivity. Energy chips were produced for \$19.19 green t⁻¹ onboard truck in the Integrated treatment and \$17.93 green t⁻¹ in the Chip treatment. Energywood harvesting costs were higher in this study than in previous research that employed loggers with less expensive, more fuel efficient equipment. This suggests that high capacity, wet-site capable loggers may not be able to economically harvest and transport energywood without a substantial increase in energywood prices.

This study suggests that the southern wood supply chain is in position to benefit from a vibrant wood-to-energy market. Landowners should benefit from an additional market for small-

diameter stems. This study shows that high production, wet-site capable loggers should not harvest energywood until prices for this material appreciate considerably. Wet-site loggers have very expensive equipment with high hourly fuel consumption rates and this study documented that energywood production was not sufficiently high to offset the high hourly cost of owning and operating this equipment. Nevertheless, a wood-to-energy market should benefit harvesting contractors in general because unless the forest products industry contracts further, loggers can continue to harvest and deliver roundwood to mills as they do at present and those properly equipped for energywood harvesting at low cost may be able to profit from a new market. The forest products industry has the largest potential downside of any member of the southern wood supply chain. This study documents widespread anticipation of competition between the forest products and wood-to-energy industries. However, to date there has been minimal wide-scale competition between the forest products and wood-to-energy industries. It is possible that the wood-to-energy industry will complement, rather than compete with the forest products industry, and thereby benefit each member of the southern wood supply chain.

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CONTRIBUTION OF AUTHORS

Dr. Chad Bolding established the methodological framework for conducting the research documented in this dissertation. He also provided assistance in reviewing each manuscript. Dr. Mike Aust assisted in the development of research methodology and also reviewed each manuscript. Dr. Bob Smith assisted in the development of the surveys presented in chapter 2 and 3 and also reviewed each manuscript. Dr. Horcher provided input in the methodology employed in chapter 4, and also assisted with manuscript review. Each committee member reviewed and approved the research methodology employed in this study.

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ANTICIPATED IMPACT OF A VIBRANT WOOD-TO-ENERGY MARKET ON THE U.S. SOUTH'S WOOD SUPPLY CHAIN

1.0 INTRODUCTION

The wood-energy market represents an opportunity to produce electricity, heat, and transportation fuels from a renewable resource, while simultaneously reducing oil imports, stimulating rural economies, and promoting energy security (Zerbe, 2006; Gan and Smith, 2007; Perez-Verdin et al., 2008). As a consequence, federal and state governments have introduced incentives and subsidies to encourage energy production from wood (United States Department of Energy [USDE], 2008a; USDE, 2008b; Database of State Incentives for Renewables and Efficiency [DSIRE], 2011). Multiple studies have quantified the amount of wood available to produce energy (Walsh et al., 2000; Perlack et al., 2005; Perez-Verdin et al., 2009). Most studies assume that wood-energy facilities will use harvesting residues, urban wood residues, and other non-commercial wood and not compete with the existing forest products industry for roundwood typically used as pulpwood.

The traditional wood supply chain typically consists of landowners, loggers, and the forest products industry (Sun and Zhang, 2006). Each link in the traditional wood supply chain has changed considerably over the last two decades. In terms of forest ownership, average tract size has decreased on private forestland (Sampson and DeCoster, 2000; Butler and Leatherberry, 2004), and the forest products industry has divested itself of much of its timberland (Clutter et al., 2005). Southern loggers have become more mechanized and more productive over the last twenty years; however, concerns over an aging workforce and lack of recruitment cloud the future of the profession (Egan and Taggart, 2004; Baker and Greene, 2008). Finally, the southern forest products industry has struggled in recent years losing 30% of its sawmills and 17% of its

pulp and paper mills since the mid-1990s (Johnson et al., 2008a). The number of operational sawmills in the South has been on the decline since at least the 1970s and the number of pulpmills peaked at 116 in 1980 and has been on the decline since, with 87 still operational in 2005 (Johnson et al., 2008a).

There is considerable uncertainty regarding the impact of a vibrant wood-energy market on the traditional southern wood supply chain. The wood-energy market may represent an opportunity for landowners, harvesting contractors, and forest industry to improve profitability through the production of a new commodity. However, there is little information in the published literature regarding the costs of harvesting woody biomass for energy and possible impacts of diverting wood fiber away from forest industry mills and towards wood-energy facilities. There is concern among some in the southern wood supply chain that if urban and harvesting residues prove uneconomical to harvest and transport, wood-energy firms may be forced to compete with forest industry for roundwood, thus increasing fiber costs for traditional users. Therefore, the objective of this study is to investigate the anticipated impact of a vibrant wood-energy market on the U.S. South's wood supply chain.

1.1 Literature Review

1.1.1 Wood-Energy

Wood can be utilized as an energy source to heat individual homes, produce electricity in power plants, and fuel personal vehicles (Zerbe, 2006). There are many benefits associated with using wood for energy. For example, when wood is used in power plants in place of coal it can lower fuel costs and reduce emissions of sulfur dioxide, nitrous oxide, and carbon dioxide (Bergman and Zerbe, 2004). When wood is used to produce transportation fuel, it can improve energy security by reducing oil imports (Zerbe, 2006). In addition, several studies suggest that

using wood for energy can provide significant economic benefits to rural economies (Gan and Smith, 2007; Perez-Verdin et al., 2008).

According to Walsh et al. (2000) there are approximately 9 million dry tonnes of forest residues and 9.6 million dry t of urban residues available annually in the thirteen southern states. This is enough to generate 20 million megawatts of electricity (Badger and Monroe, 2007), or 6.1 billion liters of cellulosic ethanol annually (Pu et al., 2008). Conner and Johnson (2011) estimated that there are 57.1 million green t of recoverable harvesting residues available annually in the U.S. South. This is enough wood to generate 30 million megawatts of electricity (Badger and Monroe, 2007), or 9.1 billion l of cellulosic ethanol each year (Pu et al., 2008). On a smaller scale, Guo et al. (2011) found that there is sufficient hardwood pulpwood available in Tennessee to support a biorefinery with an annual production capacity of 189 million l per year without negatively impacting traditional roundwood markets. However, an incremental annual increase in energywood demand of 141,000 green t per year would result in significant increases in roundwood prices by 2030.

1.1.1.1 Wood Pellets

Wood pellets can be utilized for commercial scale heating and electricity production as well as residential heating (Pellet Fuels Institute [PFI], 2011). Between 2003 and 2008 American pellet fuel production increased by nearly fourfold (Spelter and Toth, 2009). In fact, the United States ranks in the top three, along with Sweden and Canada, in annual pellet production (Peksa-Blanchard et al., 2007).

Wood pellets can be produced from almost any form of woody biomass (Aruna et al., 1997; Lehtikangas, 2001), although ash content, and consequently slagging (deposition of fused ash inhibiting boiler performance and safety), can be greater when logging residues and bark are

used to produce pellets (Ohman et al., 2004). Pellets are most often produced from industrial wood waste such as sawdust, shavings, or ground wood chips (Peksa-Blanchard et al., 2007; Spelter and Toth, 2009). The conversion of raw material to pellets consists of the following steps: screening, grinding, drying, pelletizing, cooling, sifting, and packaging (Peksa-Blanchard et al., 2007). This process creates dense, uniform pellets that can be utilized for fully automatic heating in boilers or stoves.

1.1.1.2 Electricity Generation

Twenty-nine states, plus the District of Columbia, have enacted renewable electricity standards (RES) that require utilities to produce a certain amount or a percentage of their electricity from renewable sources by a target date (DSIRE, 2011). Eight other states have voluntary RES goals. Only four southern states, North Carolina, Oklahoma, Texas, and Virginia have renewable electricity standards or goals. In general, the South has been less proactive in terms of renewable energy policies and generally has a less favorable view of incentives, subsidies, and regulations than other parts of the country (Aguilar and Saunders 2011; Becker et al., 2011).

In 2009, the thirteen southern states generated a combined 1.62 billion megawatt hours of electricity, and only 19.4 million megawatt hours (1.2%) were generated from wood or wood-derived fuels (Energy Information Administration [EIA], 2011). Coal and natural gas are responsible for 72% of the South's electricity generation (Figure 1.1); therefore, replacing coal with wood represents a tremendous opportunity to supplement fossil energy with energy from a renewable source.

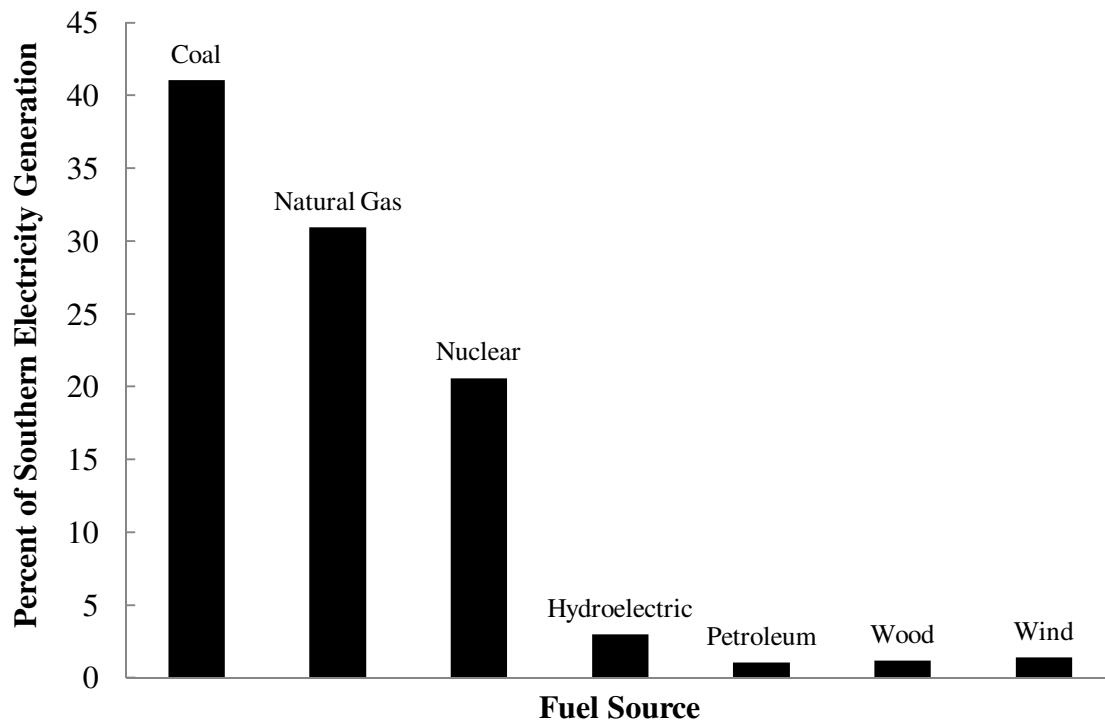


Figure 1.1: Electricity generation in the U.S. South by fuel source (EIA, 2010).

The four most common ways that electricity is generated from wood are: direct combustion, wood gasification, cogeneration, and cofiring (Forest Products Laboratory [FPL], 2004). In direct combustion, wood is burned and the resulting heat is transferred to a steam or hot water boiler and the steam generated is used to turn turbines that produce electricity. In gasification, wood is burned in the absence of oxygen in order to produce gases that can then be combusted to produce heat for a boiler or the gases can be filtered to power internal combustion engines.

Cogeneration, or combined heat and power (CHP) is the production of heat and electricity simultaneously (FPL, 2004). The forest products industry owns a majority of the cogeneration capacity in the United States (Bain and Overend, 2002) and its installation in the

1970s and 1980s allowed the pulp and paper industry to reduce its fuel oil consumption by half between 1972 and 1984 (Koning and Skog, 1987).

Cofiring is the simultaneous combustion of woody biomass and coal in a power plant (FPL, 2004). Cofiring can reduce overall fuel costs in some areas, reduce harmful emissions, reduce greenhouse gas emissions (Bergman and Zerbe, 2004), and meet renewable portfolio standards. This approach is the least expensive and lowest risk method of producing energy from wood (Tillman, 2000). The capital costs associated with installing cofiring capabilities range from \$50-\$100 per kilowatt of biomass capacity if biomass is blended with coal prior to combustion; or \$175-\$200 per kilowatt of biomass capacity if biomass is fed into the boiler separately (Hughes, 2000). In order for cofiring to be economically attractive, wood and wood waste should be at least 20% cheaper than coal on a thermal basis (Federal Energy Management Program, 2004).

Converting coal-fired facilities to cofiring or wood-fired facilities can benefit rural economies. This is of particular importance in the South, where 60% of counties are classified as rural (Mayfield et al., 2007). A study by Perez-Verdin et al. (2008) found that in Mississippi the conversion of a 100 MW coal-fired power plant to a wood-fired facility would generate 281 jobs directly and result in more than \$64 million of gross economic output. In addition, a study by Gan and Smith (2007) found that electricity generation from wood in East Texas would result in 150 new jobs and \$183 million of gross economic output. However, if electricity rates increased as a result of replacing coal with wood, jobs would likely be lost in other sectors, including the coal industry.

Electricity is produced from many forms of wood and wood waste including: hogged fuel, bark, whole tree chips, and black liquor (Zerbe and Skog, 2007). However, under some

circumstances bark can cause significant problems during cofiring applications because of its stringiness (Tillman, 2000). Of course, the ability of a plant to burn multiple forms of wood and wood waste helps ensure a constant and inexpensive supply (Van-Belle et al., 2003).

1.1.1.3 Transportation Fuel

Wood can be used to produce a number of transportation fuels such as ethanol, methanol, gasoline, diesel, and hydrogen (Zerbe, 2006). There has been considerable research conducted and money invested to promote the use of cellulosic ethanol. In 2007, the U.S. Department of Energy agreed to invest up to \$385 million in six biorefineries that would produce 492 million l of cellulosic ethanol annually (U.S. Department of Energy [USDE], 2007). Of these six, only one will use wood as its feedstock. In January 2008 the Department of Energy pledged \$114 million in support of four biorefinery projects, three of which will use wood and wood-waste as a feedstock (USDE, 2008b). In 2008 the Department of Energy announced up to \$86 million in additional investment in three small scale refineries (USDE, 2008a). One of these projects is a biorefinery that will be built into an existing pulp mill in Maine. In total, between 2007 and 2008 the Department of Energy pledged more than \$1 billion in direct investment in biofuel refineries.

In terms of production costs, cellulosic ethanol may never become cost-competitive with fossil fuels, sugar cane ethanol, methanol, or hydrogen (Hamelinck et al., 2005). However, cellulosic ethanol has important advantages over each of these fuel sources. For instance, cellulosic ethanol is produced domestically and could reduce oil imports. Secondly, cellulosic ethanol could be more easily implemented in existing vehicles than either hydrogen or methanol. Finally, cellulosic ethanol has greater energy density than methanol and is non-toxic (Zerbe, 2006).

The economic viability of cellulosic ethanol is largely dependent on feedstock cost, which accounts for 35-50% of production costs (Hess et al., 2007; Nesbit et al., 2011). Of course, economic viability would also be enhanced by predicted improvements in efficiency (Hamelinck et al., 2005). Kocoloski et al. (2011) found that 11 gigaoliters of cellulosic ethanol could be produced annually from forest thinnings at a cost of \$0.80 l⁻¹ gasoline equivalent or less. This study also suggested that the USDA Forest Service and other agencies could net \$1 billion dollars per year from these harvests and reduce annual wildfire damage by \$150 million. Another study found that cellulosic ethanol could be produced from slash pine (*Pinus elliottii* Engelm.) for the gasoline equivalent cost of \$0.94 l⁻¹ using the two-stage dilute sulfuric acid process and \$0.46 l⁻¹ gasoline equivalent using the proposed synthesis gas ethanol catalytic conversion process (Nesbit et al., 2011).

Cellulosic ethanol can be produced from wood containing bark, although bark can reduce ethanol yield (Robinson et al., 2002). In contrast, the production of methanol and bio-oil require “clean” wood chips because of the high ash content of bark (Polagye et al., 2007). The ability to use “dirty” chips is of paramount importance in maintaining a constant and inexpensive fuel supply because a significant proportion of the woody biomass available in the southeast consists of logging residues, fuel treatment by-products, and urban residues that often have high bark content (Perlack et al., 2005). Furthermore, if energy facilities require “clean” chips, this will increase the likelihood that they will compete with forest industry for roundwood.

Like electricity generation, the production of transportation fuels could provide a stimulus to rural economies. Perez-Verdin et al. (2008) found that the construction of a biofuels facility producing 197 million l per year in Mississippi would create 908 direct jobs and \$150 million in gross economic output. Similarly, Bailey et al. (2011) estimated that the installation of

six biorefineries with an annual capacity of approximately 190 million l in Alabama would result in \$447 million in total economic output and create 2,600 new jobs, 890 of which would be in the logging sector. Of course, it is unknown whether the construction of a biofuels facility or a wood-fired power plant would result in net job creation and economic output. It is possible that the construction of a biofuels facility or wood-fired power plant would simply replace jobs and economic output from other sectors.

1.1.2 Forest Products Industry

The forest products industry makes a significant contribution to the U.S. economy employing nearly 900,000 people and contributing over \$175 billion to the nation's economy each year (American Forest and Paper Association, 2011). However, the industry has struggled of late as a result of foreign competition (Collins et al., 2008), overcapacity, and soft demand (Wear et al., 2007).

Southern forest industry consists of sawmills, veneer mills, pulpmills, composite mills (OSB etc.), and other mills (poles, posts, etc.). Of these five industry segments, only composite mills have experienced consistent growth over the last two decades (Johnson et al., 2008a). Most industry segments have lost mills over the past decade, and some have cut production.

The southern pulp and paper industry has lost 17% of its mills and cut production by 10% since the mid-1990s (Johnson and Steppleton, 2008). In addition, the number of southern sawmills has declined by 60% since 1970 and by 30% since 1995 (Johnson et al., 2008a). Mill closure and consolidation have been found in both the hardwood and softwood sectors (Bowe et al., 2001; Spelter et al., 2007). However, in contrast to pulpwood production, sawtimber production has actually increased by 6% since the mid-1990s (Johnson et al., 2008b), suggesting

that mill closures allowed surviving mills to increase capacity and take advantage of economies of scale and improved utilization technology.

Between 1995 and 2001 American forest industry's share of domestic markets declined by 29% (Collins et al., 2008). The sectors hurt the most were pulp and paper, plywood, oriented strand board (OSB), softwood lumber, and household furniture. According to Collins et al. (2008), the primary reasons for this decline were a strong U.S. dollar from 1996 to 2002, OSB's replacement of plywood and insufficient domestic production, more efficient foreign mills, and the outsourcing of furniture manufacturing to China.

All of the aforementioned trends have carried over into the southern timber market. Weak demand coupled with an increase in timber supply led to a decline in real softwood pulpwood prices between 1998 and 2004 (Wear et al., 2007). Over the same period, hardwood pulpwood, hardwood sawtimber, and softwood sawtimber prices all failed to increase. Between 2004 and 2010, prices for pine sawtimber and chip-n-saw declined noticeably while softwood pulpwood, hardwood pulpwood, and hardwood sawtimber experienced modest nominal gains (Timber Mart-South, 2010). Stable or declining stumpage prices are not necessarily a problem for forest industry as it enables them to supply their mills at low cost, but stable or declining stumpage prices serve as a poor incentive for landowners to continue investing in timber production and reforestation.

1.1.3 Forestland Ownership

Over the last decade forestland ownership may have undergone the greatest change of any member of the wood supply chain. Traditionally, southern landowners consisted of three groups: non-industrial private forest (NIPF) landowners, vertically integrated forest products firms, and government holdings. However, over the last decade many forest products

corporations sold most of their timberland, which was primarily acquired by real estate investment trusts (REITs) and timberland investment management organizations (TIMOs) (Wear and Greis, 2002; Clutter et al., 2005).

1.1.3.1 Corporate Forest Owners

For years forest industry has faced criticism from Wall Street about its return on investment (Yin et al., 1998). There was growing pressure during the 1990s for companies to consolidate and focus on core business components. This led many firms to sell their timberland outright or restructure their land holding businesses. At the same time, timberland became a popular investment for institutional investors. During the 1980s and 1990s TIMOs and REITs increased their holdings by more than 1.6 million ha (Wear and Greis, 2002). Caulfield (1998) found that in all periods from 1981-1996 portfolios holding timberland outperformed portfolios without timberland at most risk levels. Furthermore, Cascio and Clutter (2008) found that southern timberland holdings have performed above the level suggested by their risk. Therefore, with mounting pressure on the forest products industry to consolidate their businesses, and institutional investors eager to hold timberland, many forest products companies divested themselves of their timberland.

It is hypothesized that the new forest landowners (TIMOs, REITs, etc.) will be more sensitive to price changes in deciding when to sell timber (Wear et al., 2007). This could have several implications. First of all, TIMOs are more likely to time their harvests based on historical market trends and current stumpage prices than forest products companies linked to a processing facility (Zinkhan, 1993), which may make it more difficult for mills to procure wood at market prices during economic downturns. Secondly, in the absence of wood purchase agreements, the

new forest landowners will have the option of selling timber to bioenergy companies if they offer higher prices. This could lead to greater competition for wood and increases in stumpage prices.

1.1.3.2 Non-Industrial Private Forest Landowners

Fifty-eight percent of southern forestland is owned by family forest landowners and 28% is owned by forest industry, TIMOs, and REITs (Butler, 2008). With these extensive timberland holdings, family forest owners will play a large role in determining the future of both forest industry and wood-energy. In contrast to forest industry, NIPF owners, which includes both family forest owners as well as timber companies that do not own processing facilities, have not been responsive to market signals to supply more or less timber. A study by Liao and Zhang (2008) found supply price elasticities of 0.70 for softwood sawtimber and 0.90 for softwood pulpwood for forest industry. The same study found supply price elasticities of 0.29 and 0.32 for softwood sawtimber and pulpwood, respectively, for NIPF owners. The lower elasticity values for NIPF owners show that this group is less likely to provide more timber during times of timber scarcity and less likely to curtail harvesting during times of surplus, compared to forest industry. In addition, government programs intended to encourage timber production on NIPF lands have generally been ineffective in increasing harvest levels (Kluender et al., 1999).

The number of forest landowners nationwide is increasing, and consequently average tract size is decreasing. Ninety-four percent of U.S. forest landowners own less than 40 ha and the average parcel size is just 10 ha (Sampson and DeCoster, 2000). The Southern Forest Resource Assessment found that urbanization will have a greater impact on the health and extent of southern forests than any other factor (Wear and Greis, 2002). It is estimated that between 2000 and 2050 urban land will increase from 3.1% to 8.1% of total land area nationwide (Nowak and Walton, 2005). During this period all of the southern states, with the exception of Oklahoma,

are projected to lose more than 100,000 ha of forestland. Furthermore, North Carolina, South Carolina, and Florida are projected to lose 10-20% of their forested area.

Increasing urbanization is an important consideration for both forest industry and wood-energy firms as it relates to procuring a continuous supply of timber. Urbanization can lead to both a long run decrease in timber supply as land is taken out of timber production, and also a decrease in short run supply as increases in land clearing activities fail to offset decreases in silvicultural treatments (Barlow et al., 1998). Furthermore, the probability of commercial forestry taking place is directly related to population density. As population density approaches 58 people km⁻², the probability of sustainable timber production approaches zero (Wear et al., 1999). At population densities of 27, 17, and 8 people km⁻², the probability of traditional forestry is 25%, 50%, and 75%, respectively. Furthermore, as parcelization occurs, the costs of all management activities increase on a per unit basis. On tracts smaller than 4-8 ha, forest management may be unlikely because of high costs (Cubbage, 1983). Of course, increased productivity of pine plantations (Fox et al., 2007) has offset some of the negative impacts of reduced tract sizes by increasing wood production per ha. However, despite increases in productivity, reduced parcel size has reduced the volume harvested per tract in many cases. For example, Moldenhauer and Bolding (2009) found that reduced parcel size in South Carolina is forcing loggers to move more often and is encouraging them to reduce the size of their operations in order to reduce fixed costs.

To date there has been no decline in timber availability because losses to urbanization have been more than offset by the conversion of marginal agricultural lands to forest and the increased productivity of pine plantations (Wear et al., 2007). It is estimated that pine plantation area will continue to increase and that productivity will continue to rise as well, allowing for

increased harvest levels (Alig et al., 2002). It remains to be seen how the balance between forest area, productivity, and demand for timber will play out in the future.

Past research indicates that forest landowners are willing to sell wood for energy use. Weyerhaeuser, a large corporate landowner, has developed a joint venture with Chevron Corporation to develop wood to liquid fuels technology (Gonzalez, 2008). Recent surveys of private forest landowners in the U.S. South indicate that a majority of these landowners are willing to sell timber for energy use (Joshi and Mehmood, 2011; Paula et al., 2011).

1.1.4 Logging Industry

Both forest industry mills and wood-energy facilities rely on harvesting contractors to harvest and transport wood to their facilities. Logging productivity and mechanization has increased dramatically over the past twenty years. The average weekly production for logging firms in Georgia increased by 83% from 1987-2007 (Baker and Greene, 2008). In addition, average production per man hour increased by over 50% during this same period. However, a reduction in clearcutting and stable or declining average tract size will likely increase logging costs in the future. Smaller tract sizes result in more frequent moves, which increase per ha logging costs (Greene et al., 1997; Moldenhauer and Bolding, 2009). Nonetheless, across the southeast, between 1972 and 2001 loggers experienced increased profit margins for hardwood pulpwood, hardwood sawtimber, and softwood sawtimber, while experiencing reduced profit margins for softwood pulpwood (Sun and Zhang, 2006). However, Stuart et al. (2010) found evidence of decreasing returns to scale in the eastern logging industry from 1988 through 2007. The authors indicated that in order for harvesting contractors to be successful they must focus on profitability and efficiency, rather than simply maximizing production.

For many years, logging has been a family affair; however, this may be changing. Egan and Taggart (2004) found that 69% of New England loggers would not recommend logging to their children, despite having strong family ties to the profession. Baker and Greene (2008) found the average age of logging owners in Georgia increased by 4.5 years between 1992 and 2007. This is not surprising given the aging “baby boomer” generation, but the lack of recruitment of new owners is of concern for the future of the industry. Loggers in New England are also concerned about recruiting new workers and suggested society’s negative attitudes toward logging, low wages, and the younger generation’s aversion to working in the woods are obstacles to recruitment (Egan and Taggart, 2004).

Despite concerns about the long term health of the logging industry, there is currently excess logging capacity in the southeast. At present, the South is utilizing only 65% of its logging capacity (Greene et al., 2004). Excess logging capacity costs \$1.83 t⁻¹ of delivered wood, and eliminating this inefficiency would save \$430 million per year. The primary causes of this inefficiency are mill quotas, mill handling, mill closure, weather, and planning. This excess capacity suggests that the logging profession may be in position to take advantage of emerging opportunities to supply wood to bioenergy facilities, assuming the profession is able to maintain an adequate workforce in the long term.

1.1.5 Woody Biomass Harvesting

1.1.5.1 Operational Considerations

Watson and Stokes (1989) recognized four methods of harvesting woody biomass for energy: 1) using a specialized machine to harvest logging slash and non-commercial stems, 2) post-harvest operations following conventional logging, 3) pre-harvest operations prior to conventional logging, and 4) integrated operations harvesting roundwood and woody biomass

simultaneously. Past research indicates that 1-pass systems are significantly less expensive per tonne than 2-pass systems (Miller et al., 1987; Stokes et al., 1984; Stuart et al., 1981). Watson and Stokes (1989) found that the cost of energywood was reduced by 30% using an integrated harvesting system compared to a pre-harvest system. However, the cost of harvesting roundwood pulpwood and sawlogs was reduced following pre-harvesting. Miller et al. (1987) found that the cost of energywood was 40% less using integrated harvesting compared to a pre-harvest system. Post-harvesting systems are the most expensive option for harvesting energywood and typically recover less biomass than integrated systems, but typically recover more of the available biomass than the pre-harvest method (Stokes and Sirois, 1989). Stokes et al. (1984) found that the integrated approach resulted in the least cost and highest biomass utilization. Chipping costs, however, were higher for the one-pass system than the two-pass system because of lower chipper utilization. In addition, if energy facilities offer higher prices for dry material, this serves as an incentive for harvesting contractors to use post-harvest methods (Dirkswanger et al., 2011).

Once woody biomass is recovered and brought to a landing, there are five alternatives for processing: 1) chipping, 2) chunking, 3) crushing, 4) bailing/bundling, and 5) grinding/shredding/hogging (Stokes and Sirois, 1989). Chunking and crushing have seen prototypes developed, but have not been utilized in commercial operations. Bailing, or bundling, has not been widely used in America, but bundling is becoming increasingly popular in Europe (Karha and Vartiamaki, 2006). One of the advantages of bundling is that the bundles can be stored for eight months or more without a reduction in feedstock quality (Patterson et al., 2008), whereas chips tend to decline in quality when stored for long periods. Karha and Vartiamaki (2006) found that four different bundling machines averaged 18 bundles per hour which equates to approximately 6.8 t per operating hour. A study in France found that these machines could

bundle between 11 and 24 bundles, or composite residue logs, per machine hour which equates to 5-9 t per machine hour (Cuchet et al., 2004). In a case study in Arkansas, Patterson et al. (2008) found that between 14 and 36 bundles could be produced each hour in the southern US, excluding delays. The cost of these bundles varied from \$13.56-\$35.52 per green t. Bundling costs were lowest for first thinning (\$13.56 green t⁻¹) and second thinning (\$15.65 green t⁻¹), and highest for clearcuts (\$21.97 green t⁻¹) and cut-to-length row thinning sites (\$35.52 green t⁻¹). The authors suggested that the high cost in the clearcut was a result of large water oak (*Quercus nigra* L.) limbs that the machine had difficulty processing. On the cut-to-length site, the bundler had trouble accessing the material left behind in the forwarder trail, which reduced its productivity.

Chipping is by far the most common method of processing woody biomass for energy in the southeast. Often, residues are chipped on the harvest site, delivered to a forest products facility, and then further processed by a hog before being utilized in a boiler (Stokes and Sirois, 1989). Westbrook et al. (2007) found that an integrated approach to harvesting woody biomass could deliver dirty chips up to 64 km for \$12 t⁻¹ if only limbs and tops were used and \$13 t⁻¹ if limbs, tops, and non-merchantable stems were used during clearcutting applications. These results suggest that wood chips can be delivered for nearly \$9 t⁻¹ less than composite residue logs can be produced at the roadside (Patterson et al. 2008). When transportation costs are included for the composite residue logs, the cost differential exceeds \$11 t⁻¹. Similarly, Mitchell and Gallagher (2007) found that during a fuels treatment operation dirty chips could be produced at the roadside for \$10.12 green t⁻¹, which is less expensive than bundles could be produced during any of the four case studies by Patterson et al. (2008).

With current prices for fuelwood significantly lower than prices for pulpwood and sawtimber, harvesting fuelwood must augment the harvesting of traditional products without reducing the production of higher value products. Baker et al. (2010) found that adding a small chipper to a traditional tree length system did not reduce roundwood production when only limbs and tops were utilized. Unfortunately, this method yielded less than 12 t ha⁻¹ of fuel chips. When non-merchantable stems were utilized, chip production increased to more than 24 t ha⁻¹ in clearcuts and 45 t ha⁻¹ during thinning. When non-commercial stems were utilized, roundwood production was not reduced in clearcuts, but roundwood production had the potential to be reduced by 50% during thinning. This suggests that clearcuts are the most economical source of energywood.

1.1.5.2 Site Preparation Savings

Harvesting woody biomass for energy can reduce site preparation costs through greater utilization. Watson et al. (1984) found that conventional harvesting removed only 59% of standing volume, whereas a one-pass system which harvested both traditional products and energywood removed up to 90% of standing volume. This study also found that site preparation costs could be reduced by \$143-\$190 ha⁻¹ (60-80%) (1984 dollars) when harvesting woody biomass using a one-pass system. This savings estimate assumes that energywood harvesting allows a shear-rake-pile-disc treatment to be replaced with a one or two disc treatment. Another study found that site preparation costs could be reduced by \$29-\$226 ha⁻¹ (1985 dollars) depending on the method of site preparation (Stokes and Watson, 1986). Savings of \$29 ha⁻¹ were found with herbicide treatments and savings of \$226 ha⁻¹ were found with single disc treatments.

Of course, utilization during conventional harvests has improved since the 1980s, so site preparation savings due to biomass harvesting may be less today than during the 1980s. However, a 2006 study found that raking costs were reduced by nearly \$57 ha⁻¹ as a result of utilizing limbs, tops, and non-merchantable stems (Westbrook et al., 2007).

1.1.6 Potential Impacts of a New Supply Chain Participant

Two areas that could be impacted by a vibrant wood-energy market are procurement practices and stumpage prices, both of which will impact the long term profitability of the forest products industry. Procurement practices are already changing as a result of forest industry's divestment of timberland, and will have to evolve further if wood-energy companies become major buyers in the southern timber market.

Traditionally, there have been four methods of procuring wood for a mill: fee land, lease land, landowner assistance programs, and open market purchases (Kronrad et al., 1985). However, as a result of industry restructuring, most wood must now be bought on the open market. This makes forest industry more vulnerable to increases in stumpage prices if wood-energy companies enter the market for roundwood. This impact is already being felt in localized markets but has yet to impact the industry as a whole (Bowyer, 2008).

If stumpage prices rise as a result of wood-energy ventures it may negatively impact the forest products industry, but will benefit both landowners and loggers. Nonetheless, the forest products industry is in position to profit from a wood-energy market. The forest products industry already has a supply chain in place which it could use to produce energy as well as traditional products (Rodden, 2008). Several authors have investigated the possibility of forest products industry mills integrating cellulosic ethanol, electricity, chemical, and pulp and paper

production as a means of optimally using each piece of wood that enters a mill (Frederick et al., 2008; Winandy et al., 2008).

1.1.7 Conclusion

There is currently a plethora of information on forest ownership, harvesting contractors, the forest products industry, and especially biomass energy. However, noticeably absent from the literature are studies that link the emerging wood-energy market to the rest of the wood supply chain. Nonetheless, if the wood-energy market expands, it will certainly have implications for all forest-based industry (Bowyer, 2008). Failure to recognize the wood-energy market as a part of the wood supply chain is equivalent to ignoring a potential customer, or failing to address a new competitor.

The situation is exacerbated by the unprecedented changes in the wood supply chain over the last two decades. There is significant uncertainty in forest-based industry, the wood-energy market notwithstanding. This underscores the need for new research to measure the expectations of wood supply chain participants regarding the wood-energy market. The only way to make sound decisions is by making decisions based on accurate information about current conditions, and reasonable expectations about the future. Therefore, research generating accurate information regarding wood supply chain participants' expectations for wood-based energy and accurate estimates of woody biomass harvesting costs will enable foresters, forest industry companies, bioenergy firms, and government officials to make more informed decisions.

1.2 Objectives and Organization

This dissertation is organized into five chapters. The first chapter introduces the research topic and provides a literature review of recent trends in the southern wood supply chain as well as background information on the wood-to-energy market. Chapters two through four are

designed to be stand-alone manuscripts that have been, or will be, submitted to peer-reviewed journals. The final chapter will summarize the results presented in the preceding chapters.

The second chapter outlines recent changes in the southern wood supply chain and presents the results of a survey of consulting foresters from the thirteen southern states. The objectives of this chapter were to report consulting foresters' insight into the following issues: 1) the anticipated expansion of the wood-to-energy market and its impact on landowners and forest industry mills, 2) changing forest ownership and average harvest tract size, 3) mill closure and its impact on the profitability of timber sales, and 4) harvesting contractors' response to difficult markets and the adequacy of southern logging capacity. This manuscript was written by Joseph Conrad, with contributions from Dr. Chad Bolding, Dr. Mike Aust, and Dr. Robert Smith. This manuscript was published in *Forest Policy and Economics* (Conrad et al., 2010). The right to include the published manuscript in this dissertation is retained by the authors (Elsevier, 2011).

The third chapter presents the results of a survey of forest landowners, forest products industry mills, and wood-to-energy facilities. The objectives of this chapter were to: 1) examine the expected impact of a vibrant wood-to-energy market on stumpage prices and procurement practices, 2) examine the expected impact of a wood-to-energy market on the profitability of landowners and the forest products industry, 3) examine the attitudes of landowners and forest industry personnel toward government policies encouraging wood-based energy, and 4) examine landowners' expectations for wood-based energy and evaluate their willingness to sell timber to energy facilities. This manuscript was written by Joseph Conrad, with contributions from Dr. Chad Bolding, Dr. Robert Smith, and Dr. Mike Aust. This manuscript was published in *Biomass and Bioenergy* (Conrad et al., 2011). The right to include the published manuscript in this dissertation is retained by the authors (Elsevier, 2011).

The fourth chapter presents the results of a designed operational study that investigated the productivity and cost of harvesting energywood from a southern pine clearcut. The objectives of this chapter were to: 1) quantify the difference in roundwood harvesting costs between harvesting roundwood only and integrating roundwood and energy chip production, 2) quantify the difference in hourly production rates and energy chip harvesting costs for stand-alone energywood production versus integrated roundwood and energy chip production, 3) investigate whether adding a chipper to a tree-length southern pine harvesting operation reduces hourly and per hectare roundwood production, 4) compare woody biomass utilization between roundwood only harvesting, energy chip harvesting, and integrated roundwood and energy chip harvesting, and 5) compare energy chip harvesting costs with high-production, wet-site capable loggers to past research that employed loggers with smaller capital investments. This manuscript was written by Joseph Conrad, with contributions from Dr. Chad Bolding, Dr. Mike Aust, Dr. Robert Smith, and Dr. Andy Horcher. This manuscript will be submitted to a peer-reviewed journal for publication.

The final chapter synthesizes the results of chapters two through four and seeks to draw conclusions about the anticipated impact of a vibrant wood-to-energy market on the U.S. South's wood supply chain. This chapter was written by Joseph Conrad.

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2.0 WOOD-TO-ENERGY EXPANSION, FOREST OWNERSHIP CHANGES, AND MILL CLOSURE: CONSEQUENCES FOR U.S. SOUTH'S WOOD SUPPLY CHAIN

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2.1 Abstract

The U.S. South's wood supply chain has undergone major changes over the past two decades in terms of forestland ownership and forest industry structure. Recent interest in producing energy from wood has raised questions about how a vibrant wood-energy market will impact the traditional southern wood supply chain. By using a survey of consulting foresters, this study examined how harvest tract size, forest ownership, and forest industry structure have changed within the U.S. South and how foresters expect the wood-energy market to impact the wood supply chain in the future. Results indicate that there are currently inadequate markets for timber as a result of expanded timber supply and reduced forest products industry capacity. Only 12% of respondents reported having sold timber to an energy facility, although 98% of respondents reported their clients are willing to sell to an energy facility. In addition, 89% of respondents suggested that a vibrant wood-to-energy market will provide an additional market for timber and will not displace forest products industry capacity. This study found excess logging capacity as evidenced by frequent mill quotas; however, an aging logging workforce and tight credit markets make logging capacity uncertain in the long term as the U.S. economy rebounds from recession and wood-energy demand increases. The percentage of respondents reporting an average harvest tract size over 16 ha (40 ac) decreased from 95% in 1999, to 70% in 2009, and only 47%

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southern wood supply chain is in position to take advantage of an expanded wood-energy market; however, decreasing harvest tract sizes, urbanization, and a decline in the forest products industry are lingering issues for landowners, mills, foresters, and loggers in the South.

2.2 Introduction

The U.S. South's wood supply chain, which consists of landowners, harvesting contractors, and processing facilities (Sun and Zhang, 2006), has undergone substantial changes over the past two decades in terms of forest ownership and forest industry structure. In addition, wood-based energy is anticipated as a new component of the wood supply chain and will likely affect traditional participants (Bowyer, 2008). However, it is uncertain how these changes will impact the competitiveness and profitability of the southern wood supply chain. Therefore, the objectives of this study were to identify major changes in the U.S. South's wood supply chain and, through a survey of consulting foresters, analyze how these changes have and will impact foresters, mills, landowners, and harvesting contractors.

Specifically, this study will report consulting foresters' insight into the following issues: 1) the anticipated expansion of the wood-energy market and its impact on landowners and forest industry mills, 2) changing forest ownership and average harvest tract size, 3) mill closure and its impact on the profitability of timber sales, and 4) harvesting contractors' response to difficult markets and the adequacy of southern logging capacity. Consulting foresters provide a unique perspective on forest ownership patterns, forest industry structure, and wood-energy expansion because they commonly interact with landowners, forest products industry personnel, harvesting contractors, and timber buyers. Furthermore, consulting foresters assist landowners with silvicultural decisions and timber sales that directly impact fiber supply for both the forest products and wood-energy industries. Finally, since 86% of southern forestland is privately

owned (Butler, 2008), consulting foresters have the potential to be involved in a large proportion of forest management decisions.

2.3 Recent Trends in the Southern Wood Supply Chain

2.3.1 Wood-Based Energy

Wood can be utilized as an energy source to heat individual homes, produce electricity in power plants, and provide fuel for personal vehicles (Zerbe, 2006). Three of the most promising uses of wood for energy are as wood pellets for home or business stoves, as feedstock in wood-fired or co-fired electricity power plants, and as feedstock in the production of biofuels. Perlack et al. (2005) reported that 334 million dry tonnes of woody biomass from America's forests could be produced annually for energy without negatively impacting the production of traditional forest products. According to Walsh et al. (2000), there are approximately 9 million dry tonnes of forest residues, 9.6 million dry tonnes of urban residues, and 650,000 dry tonnes of mill residues available annually in the thirteen southern states at prices of \$33, \$22, and \$22 per dry tonne, respectively. This volume of wood could potentially generate 20 million megawatts of electricity (Badger and Monroe, 2007), or 6.8 billion liters (1.8 billion US gal) of cellulosic ethanol (Pu et al., 2008).

To date, the South has relied on coal and natural gas for approximately 75% of electricity generation. However, electricity generation from renewable sources is likely to increase substantially over the next two decades. Thirty-three states and the District of Columbia have enacted renewable portfolio standards or goals that mandate utilities to produce a certain percentage of electricity from renewable sources by a target date (Database of State Incentives for Renewables and Efficiency, 2009). These standards or goals vary from 10% renewable

generation by 2015 to 25% by 2025. However, only three southern states, North Carolina, Texas, and Virginia, currently have renewable portfolio standards or goals.

In addition to regulatory policies that encourage renewable energy, federal and state governments have made significant investments in biomass energy. All southern states have financial incentives promoting bioenergy (Alavalapati et al., 2009). Furthermore, in 2007 and 2008 the federal government pledged over \$1 billion in direct investment for biofuel refineries (USDE, 2007; USDE, 2008a; USDE, 2008b).

There is no consensus on whether wood-energy companies and forest industry mills will compete for raw material. Perlack et al. (2005) suggested that wood-energy companies will utilize mill residues, harvesting residues, urban residues, and other low-value wood and not compete with traditional forest industries for roundwood. However, they acknowledged that at high oil prices and low timber prices, pulpwood and other small diameter material could become available for energy production. La Capra Associates (2006) suggested that competition between forest industry and energy companies would drive up the price of pulpwood making it impractical for energy use unless demand from the pulp and paper industry declines significantly. Lundmark (2006) reported that in Sweden there is a threshold at which it becomes more economical to produce energy from roundwood than from harvesting residues, meaning the expansion of wood-based energy beyond a certain point will likely put upward pressure on stumpage prices for roundwood. Galik et al. (2009) found that in North Carolina, South Carolina, and Virginia, if demand for woody biomass exceeds the supply of forest residues there will be a subsequent spike in raw material costs which will eliminate marginal wood consumers. However, Conrad and Bolding (2011) found that large scale competition for resources between the forest products and wood-energy industries is unlikely in Virginia, at least in the short term,

because of state regulatory policies that cap the amount of wood that can contribute toward the renewable portfolio goal at 1.4 million green tonnes, and the absence of biofuel refineries that would be eligible for subsidies and not subject to the cap. In addition, Benjamin et al. (2009) suggested that an expansion of the wood-energy market in the northeast is likely to create competition between the pulp and paper industry and energy companies.

2.3.2. Forest Ownership

Fifty-eight percent of southern forestland is owned by family forest landowners and 28% is owned by forest industry, timberland investment management organizations, and real estate investment trusts, with the remaining 14% of forestland owned by local, state, and the federal government (Butler, 2008). With these extensive timberland holdings, family forest owners will play a large role in determining the future of both the forest products and wood-energy industries. Nearly ninety percent of U.S. forest landowners own less than 20 ha (50 ac) and the average parcel size is just 10 ha (25 ac) (Butler, 2008). The Southern Forest Resource Assessment suggests that urbanization will have a greater impact on the health and extent of southern forests than any other factor (Wear and Greis, 2002). It is estimated that between 2000 and 2050 all of the southern states, with the exception of Oklahoma, are projected to convert more than 100,000 ha (250,000 ac) of forestland to other uses.

Increasing urbanization is an important consideration for both forest industry and wood-energy firms as it relates to procuring a continuous fiber supply. Urbanization can lead to both a long term decrease in timber supply as land is taken out of timber production, and also a decrease in short term supply as increases in land clearing activities fail to offset decreases in silvicultural treatments (Barlow et al., 1998). Furthermore, the probability of commercial forestry taking place is directly related to population density. As population density approaches 58 people per

square kilometer (150 people mi⁻²), the probability of sustainable timber production approaches zero (Wear et al., 1999). At population densities of 27, 17, and 8 people per square kilometer (70, 45, 20 people mi⁻²), the probability of traditional forestry is 25%, 50%, and 75%, respectively. Furthermore, as parcelization occurs, the cost of all management activities increase on a per unit basis. On tracts smaller than 4-8 ha (10-20 ac), forest management may not be financially attractive because of high per hectare costs (Cubbage, 1983). Moldenhauer and Bolding (2009) found that reduced parcel size in South Carolina forced loggers to move more often and encouraged them to reduce the size of their operations in order to reduce fixed costs.

To date there has been no decline in timber availability because losses to urbanization have been more than offset by the conversion of marginal agricultural land to forest and the increased productivity of pine plantations (Wear et al., 2007). It is estimated that pine plantation area will continue to increase and productivity will continue to rise, allowing for increased harvest levels (Alig et al., 2002). It is uncertain how forest area, productivity, and demand for timber will play out in the future.

There has been a substantial shift in land ownership in recent years away from traditional vertically integrated forest products companies towards Timberland Investment Management Organizations (TIMOs), Real Estate Investment Trusts (REITs), and other institutional investors. During the 1980s and 1990s TIMOs and REITs increased their timberland holdings by more than 1.6 million ha (4 million ac) (Wear and Greis, 2002). Between 1995 and 2005 nearly 7 million ha (18 million ac) of southern timberland changed hands with most of these transfers being from forest products companies to institutional investors (Clutter et al., 2005).

Hypothetically, the new forest landowners (TIMOs, REITs, etc.) may be more sensitive to price changes in deciding when to sell timber (Wear et al., 2007), and this could have several

implications. First, TIMOs are more likely to time their harvests based on historical market trends and current stumpage prices than forest industry (Zinkhan, 1993), which may make it more difficult for mills to procure wood at market prices during economic downturns. Secondly, in the absence of wood purchase/supply agreements, new forest landowners will have the option of selling timber to bioenergy companies if they offer higher prices. This could lead to greater competition for wood and increases in stumpage prices.

2.3.3. Forest Products Industry

The southern forest products industry consists of sawmills, veneer mills, pulpmills, composite (OSB etc.) mills, and other (poles, posts, etc.) mills (Johnson et al., 2008b). Of these five industry segments, only composite mills have experienced consistent growth over the last two decades; most industry segments have lost mills, and some have reduced production.

The southern pulp and paper industry lost 17% of its mills and eliminated 10% of production since the mid-1990s (Johnson et al., 2008b; Johnson and Steppleton, 2008). In addition, the number of southern sawmills has declined by 60% since 1970 and by 30% since 1995 (Johnson et al., 2008b). Mill closure and consolidation have occurred in both the hardwood and softwood sectors (Bowe et al., 2001; Spelter et al., 2007). However, in contrast to pulpwood production, sawtimber production has actually increased by 6% since the mid-1990s (Johnson et al., 2008a), suggesting that mill closure allowed surviving mills to increase capacity and take advantage of economies of scale.

Between 1995 and 2001 American forest industry's share of domestic markets declined by 29% (Collins et al., 2008). The sectors that experienced the greatest decline were pulp and paper, plywood, oriented strand board (OSB), softwood lumber, and household furniture. In addition, weak demand, in combination with an increase in timber supply, caused a decline in

real softwood pulpwood prices between 1998 and 2004 (Wear et al., 2007). During the same period, hardwood pulpwood, hardwood sawtimber, and softwood sawtimber prices all failed to increase. Between 2004 and 2009, prices for pine sawtimber and chip-n-saw declined while softwood pulpwood, hardwood pulpwood, and hardwood sawtimber experienced modest nominal gains (Timber Mart-South [TMS], 2009). Stable or declining stumpage prices are not a direct problem for the forest products industry as it enables them to supply their mills at low cost, but stable or declining stumpage prices serve as a poor incentive for landowners to invest in timber production.

2.4 Methods

In order to determine how each of the aforementioned trends has and will impact southern forestry, we conducted a survey of consulting foresters from across the U.S. South. Survey participants were selected from the list of consulting foresters maintained on the Association of Consulting Foresters (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 of the firm with an email address. For firms listed in multiple states, one representative from each state was included in the survey. Twelve consulting firms did not have email addresses, and therefore were excluded from the study. The sample size for this survey was 254.

On July 7, 2009 survey participants were mailed a pre-notice letter via first class mail notifying them that they would receive a questionnaire by email. The letter requested that participants notify survey administrators if they used a different email address than the one listed. This led to the correction of several email addresses. The questionnaire was administered

online using survey.vt.edu. A link to the survey was emailed to survey participants on July 13, July 20, and July 27, 2009.

The questionnaire consisted of 30 multiple choice questions. The questionnaire included one classification question (what state the forester practices in), thirteen questions on wood-based energy, four questions on mill closure and the adequacy of timber markets, three questions on harvest tract size, six questions on changes in land ownership, and three questions on harvesting contractors. Ten questions utilized a 5-point Likert scale (1 = strongly agree, 2 = agree, 3 = neutral, 4 = disagree, 5 = strongly disagree) and the rest were categorical in nature. The two-tailed t-test was used to analyze questions using the Likert scale to test the null hypothesis that $\bar{x} = 3$ versus the alternative that $\bar{x} \neq 3$. The two-tailed, two-sample t-test assuming unequal variance was used to test whether the mean response from states with renewable portfolio standards was equal to the mean response from states without renewable portfolio standards. Analysis of variance and the Tukey HSD test were used to determine whether or not there were statistically significant differences in responses for 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 was used to analyze nominal survey data (Rea and Parker, 2005). All statistical tests were conducted at the 5% significance level and statistical analysis was performed using Excel spreadsheets (Microsoft, 2003) and JMP (JMP, 2007).

Non-response bias was assessed using wave analysis (Armstron and Overton, 1977), which compared the responses of the first 30 participants to the last 30 participants on four questions. Due to the small sample size and the categorical nature of some of the data, the chi-square test ($\alpha = 0.05$) was used to test non-response bias.

2.5 Results and Discussion

Eight emails could not be delivered; therefore, sample size was reduced to 246. A total of 163 questionnaires were completed, for an adjusted response rate of 66.3% (Table 2.1). Twelve of thirteen states had response rates of 50% or better, with Louisiana being the only state with a response rate less than 50%. There were no significant differences observed between early and late respondents, which indicates non-response bias was not a major source of error in this study.

The results of this study will be reported in four sections. The first section will provide results relating to wood-based energy. The subsequent sections will report results relating to forest products industry mills, land ownership and harvest tract size changes, and harvesting contractors, respectively.

2.5.1 Wood-to-Energy Expansion

Fifty-five percent of respondents have perceived an expansion of wood-based energy in their state. Sixty-two percent of respondents from the Gulf Coast states (AL, LA, MS, TX) noticed an expansion of wood-based energy, compared to 54% of respondents from Atlantic Coast states (FL, GA, NC, SC, VA), and only 38% of respondents from the interior southern states (AR, OK, KY, TN); however, these differences were not statistically significant ($\chi^2 = 3.8$; $P = 0.15$). No significant differences were observed between states with and without renewable portfolio standards for any question.

It is somewhat surprising that only half of respondents have observed an expansion of the wood-energy market. Only three southern states (NC, TX, VA) have renewable portfolio standards, and coal has traditionally been significantly cheaper than other feedstocks on an energy basis (Table 2.2). However, with increasing concerns about the use of fossil fuels, especially coal; the existence of state incentives promoting renewable energy (Alavalapati et al.,

Table 2.1: Responses, number of questionnaires sent, and response rate for the thirteen southern states.

State	Responses	Sent	Response rate (%)
Atlantic Region			
Florida	5	8	62.5
Georgia	7	10	70.0
North Carolina	26	42	61.9
South Carolina	26	33	78.8
Virginia	15	21	71.4
Atlantic Region Total	79	114	69.3
Gulf Coast Region			
Alabama	17	25	68.0
Louisiana	6	18	33.3
Mississippi	22	28	78.6
Texas	10	20	50.0
Gulf Coast Region Total	55	91	60.4
Interior Region			
Arkansas	7	12	58.3
Kentucky	14	17	82.4
Oklahoma	1	1	100.0
Tennessee	7	11	63.6
Interior Region Total	29	41	70.7
U.S. South Total	163	246	66.3

Table 2.2: Comparison of the delivered price of coal (public utilities), wood, and natural gas on an energy basis (Energy Information Administration, 2009; TMS, 2007-2008). Coal prices are the average for the said region, wood prices are the average yearly price for the southeast, and natural gas prices are the average for the U.S. The following conversion factors were used: coal contains 26.7 mj/kg, natural gas contains 34.6 mj/m³, and bone dry wood fuel contains 17.7 mj/kg (assumed 50% moisture content for delivered wood) (Oak Ridge National Laboratory, 2009).

Fuel Source	2007		2008	
	\$/gj	\$/t	\$/gj	\$/t
Coal (South Atlantic) ¹	2.39	63.81	2.80	74.92
Coal (East South Central) ²	1.82	48.64	2.20	58.73
Coal (West South Central) ³	1.07	28.66	1.20	32.22
Pine pulpwood	3.17	28.02	3.41	30.14
Pine fuel chips ⁴	1.93	17.11	2.39	21.12
Hardwood pulpwood	2.99	26.42	3.36	29.72
Hardwood fuel chips ⁴	2.05	18.07	2.52	22.31
Natural gas ⁵	7.45	\$0.26/m ³	9.40	\$0.33/m ³

¹ South Atlantic region includes DE, DC, FL, GA, MD, NC, SC, VA, and WV.

² East South Central region includes AL, KY, MS, and TN.

³ West South Central region includes AR, LA, OK, and TX.

⁴ Fuel chip prices are reported as FOB Mill/Woods, meaning these prices are averages calculated using both delivered and on-board truck prices.

⁵ Natural gas prices declined significantly in 2009 to below \$5 per gj.

2009), and the threat of renewable portfolio standards and other regulations, expanded use of wood for energy is likely.

Ninety-eight percent of respondents suggested their clients would be willing to sell timber to an energy facility if a competitive price was offered, while only 2% of respondents were not sure. No respondents reported that their clients would be unwilling to sell to an energy facility. Despite a perceived willingness to sell timber to an energy facility, only 12% of respondents reported that they or their clients have sold timber to an energy facility. All foresters who had sold timber to an energy facility reported that the experience was positive. Seventeen percent of foresters in Atlantic Coast states reported that they or their clients have sold wood to an energy facility, compared to 9% for Gulf Coast states, and no foresters from the Interior states reported having sold timber to an energy facility. These differences were statistically significant ($\chi^2 = 7.0$; $P = 0.03$).

The number of foresters that reported having sold wood to an energy facility may be artificially low because consultants may have sold timber for a lump sum to a mill or a wood dealer, who then sold the harvesting residues to an energy facility. However, even when indirect sales of timber to energy facilities are considered, it appears that wood-energy markets are not available in many areas. According to the Pellet Fuels Institute (2009), there were only fifteen wood pellet mills in the thirteen southern states during the summer of 2009, and by contacting state regulatory agencies the authors were able to identify only fifteen wood-using electricity power plants operating in the thirteen southern states. The small number of respondents who reported having sold wood to an energy facility and the small number of wood-energy facilities available confirm that the wood-energy market is immature or non-existent in many areas.

The willingness of landowners to sell timber to energy facilities and the positive experience of those who have sold wood to an energy facility are positive signs for the expansion of the wood-energy industry. A survey in Sweden found that 15% of respondents who sold wood to an energy facility were negative about the experience and would not sell to an energy facility again (Bohlin and Roos, 2002). While the cause of dissatisfaction is not explicitly stated, those who chose not to sell wood for energy in the first place expressed concerns about soil fertility. Therefore, it is logical to assume that those who sold wood to an energy facility and were dissatisfied with the experience may have also been concerned about soil fertility. The experience in Sweden and the inexperience of southern landowners with wood-based energy demonstrate the importance of wood-energy facilities developing and maintaining good relationships with landowners. Furthermore, Swedish landowners' concerns about soil fertility underscore the need for research examining the environmental impact of biomass harvesting and identifying practices that minimize or mitigate negative impacts.

Sixty-six percent of respondents suggested that wood-energy firms will compete for wood with forest industry mills (Table 2.3). This finding is consistent with past research that indicates a level of wood-energy demand at which mills and energy facilities will compete for wood (Lundmark, 2006; Benjamin et al., 2009). Foresters were unsure who would be advantaged if competition were to occur between wood-energy facilities and forest industry mills. Only 10% of respondents indicated that energy facilities will have the advantage in procuring wood, which suggests that responding foresters expect the existing forest products industry to remain a primary purchaser of timber in the South. Sixty percent of respondents suggested that competition between mills and energy facilities will cause stumpage prices to increase. This finding is consistent with past studies (La Capra Associates, 2006; Galik et al., 2009).

Table 2.3: Consulting foresters' opinions about wood-based energy and its impact on the southern wood supply chain. T tests were conducted to test the hypothesis that the mean response to scalar 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
An expansion of the wood-to-energy market will improve the profitability of my clients' forestland investments. (percent)				
Agree	86	80	86	84
Disagree	11	16	10	4
Neutral/Not Sure	3	4	3	12
Mean (t= -20.1; P < 0.001)	1.92	2.11	2.00	2.00
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

Eighty-four percent of respondents expected the wood-energy market to improve the profitability of their clients' forestland investments (Table 2.3). In addition, 89% of respondents anticipated that the wood-energy market will provide an additional market for timber and will not simply displace current forest products industry capacity. These findings suggest that adequate timber exists for both the forest products and wood-energy industries and suggests that consulting foresters do not expect competition between mills and energy facilities to raise stumpage prices sufficiently to displace existing wood users. However, this study was conducted during one of the worst timber markets of the past fifty years, and so the potential for competition may be somewhat understated once traditional timber markets recover.

Sixty-seven percent of respondents anticipated that government policies, such as tax breaks and subsidies, will play a major role in determining whether wood-energy companies and forest industry mills compete for wood (Table 2.4). Foresters from the interior states were less likely to believe that the government would play a large role, but this difference was not statistically significant ($F = 0.9$; $P = 0.4$). Only 24% of respondents supported tax breaks and subsidies for wood-energy companies. A majority of respondents suggested that tax breaks and subsidies for energy companies will make mills less competitive in purchasing wood. Consultants' *laissez faire* view of government involvement in southern timber markets was contradicted somewhat by 43% of foresters supporting renewable portfolio standards. Respondents from states with renewable portfolio standards (NC, TX, VA) had a slightly higher opinion of the regulations than non-RPS states. Respondents from the interior states had the most favorable opinion of renewable portfolio standards followed by the Atlantic Coast states, with the Gulf Coast states the only region with an unfavorable view overall. However, these differences were not statistically significant ($F = 1.6$; $P = 0.21$).

Table 2.4: Consulting foresters' attitudes toward government policies encouraging wood-based energy. Responses are given in percentages and are segregated by region. T tests were conducted to test the hypothesis that the mean response to scalar 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
Government policies such as tax breaks, subsidies, targets, and mandates will play a significant role in determining whether or not forest industry mills and wood-to-energy facilities compete for wood. (percent)				
Agree	68	73	55	67
Disagree	15	7	10	12
Neutral/Not Sure	16	20	34	21
Mean (t = -10.45; P < 0.001)	2.18	2.22	2.44	2.24
I support tax breaks and subsidies for wood-using energy companies. (percent)				
Agree	24	22	28	24
Disagree	56	38	38	46
Neutral/Not Sure	24	42	34	30
Mean (t = 4.34; P < 0.001)	3.5	3.29	3.29	3.39
Tax breaks and subsidies given to wood-using energy companies will make forest industry mills less competitive in purchasing wood. (percent)				
Agree	62	53	66	60
Disagree	23	22	14	22
Neutral/Not Sure	15	25	21	18
Mean (t = -6.22; P < 0.001)	2.47	2.60	2.50	2.52
I support renewable electricity standards which mandate utilities to produce a certain percentage of their electricity from renewable sources by a target date. (percent)				
Agree	51	27	52	43
Disagree	39	47	34	41
Neutral/Not Sure	10	25	14	16
Mean (t = 0.9; P > 0.2)	3.01	3.33	2.86	3.09

Only 50% of respondents felt they were adequately informed about the opportunities and realities of wood-based energy, while 26% felt they were not adequately informed, and the remaining respondents were neutral or unsure. This suggests that University Extension Programs, continuing education programs, and especially wood-energy companies have work to do in educating landowners and foresters about wood-based energy. Bohlin and Roos (2002) suggested that buyers of forest fuels need to be active in approaching “passive manager” type landowners. This may also be true for consulting foresters managing timber for non-industrial private forest landowners (NIPF). Past research indicates that NIPF owners are not responsive to market signals to supply more or less timber (Liao and Zhang, 2008), which would further underscore the need for wood-energy companies to develop and maintain relationships with landowners and their foresters.

2.5.2 Forest Products Industry

Ninety-four percent of respondents reported a decline in the number of forest products industry mills in their area. Ninety-seven percent of respondents reported that sawmills in their area have closed or reduced capacity. Likewise, 64% of respondents reported shutdowns or capacity reductions at pulpmills, 63% at plywood or veneer mills, 62% at composite mills (OSB, particleboard, etc.), and 2% reported shutdowns or reductions in capacity at wood pellet mills.

Ninety-one percent of respondents felt that mill closures have reduced the profitability of timber sales. This response was significantly different from neutral ($T = -23.5$; $P < 0.001$). Foresters from the Interior states held a stronger opinion that mill closures had adversely impacted the profitability of their timber sales than foresters from the Atlantic or Gulf Coast states ($P < 0.05$).

Only 21% of respondents felt that there were adequate markets for their timber, while 71% felt that markets were inadequate, with the remainder neutral on the matter. This response was significantly different from neutral ($T = 9.6$; $P < 0.001$). Respondents from Gulf Coast states were most adamant that markets were inadequate; however, there was no statistically significant difference between regions ($0.05 < P < 0.10$).

These findings are not surprising as mill closures have been widely reported by past studies (Bowe et al., 2001; Spelter et al., 2007; Johnson et al., 2008b); however, this study demonstrates the widespread impact of these closures and their perceived impact on timber sale profitability. While mill closures have reduced the profitability of timber sold, timberland prices have continued to increase and, while some of this price appreciation has been a result of anticipated development, it remains to be seen whether or not mill closures will eventually reduce the value of southern timberland.

2.5.3 Forest Ownership and Changes in Harvest Tract Size

Respondents reported that the average harvest tract size has decreased across the southeast between 1999 and 2009 and tract size is expected to decrease further over the next decade (Table 2.5). Ninety-five percent of foresters reported that the average harvest tract size in 1999 exceeded 16 ha (40 ac) and 41% of foresters reported an average tract size over 32 ha (80 ac). In 2009, 60% of foresters reported average harvest tract sizes over 16 ha (40 ac), and just 14% reported averages over 32 ha (80 ac). In contrast, just 47% of foresters expected the average harvest tract size to exceed 16 ha (40 ac) in 2019, and only 10% expected the average to exceed 32 ha (80 ac).

In general, Atlantic Coast states had the smallest proportion of foresters reporting an average harvest tract size over 16 ha (40 ac), while the Gulf Coast states had the greatest

proportion of foresters reporting average harvest tract sizes over 16 ha (40 ac) (Table 2.5).

Atlantic Coast states also had the greatest shift towards smaller average tract sizes over the past decade. Furthermore, foresters from the Atlantic Coast states expected the largest shift towards smaller tract sizes between 2009 and 2019.

Table 2.5: Average harvest tract size ten years ago, today, and in ten years 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				
		<4 ha (10 ac)	4-14 ha (10-19 ac)	8-15 ha (20-39 ac)	16-32 ha (40-80 ac)	>32 ha (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 reduction in average harvest tract size corresponds with the results reported by Moldenhauer and Bolding (2009). Parcelization is a serious concern for consulting foresters as landowners with small timberland holdings may be less likely to use a consultant to market their timber. In addition, for foresters who work on a commission basis, smaller tract sizes will result in decreased revenue from individual timber sales. Of course, increased productivity of forestland, especially southern pine plantations (Fox et al., 2007), has offset some of the negative impacts of parcelization. Since landowners are paid per unit volume rather than by hectare, the volume harvested in individual timber sales has declined by less than the decline in tract size would indicate.

An overwhelming majority of consulting foresters (85%) reported a shift towards real estate development in areas previously managed for timber production (Table 2.6). The Atlantic Coast region had the greatest proportion of foresters who observed an increase in real estate development. Seventy-three percent of foresters expected the same or greater rate of conversion to development in the next decade as was experienced in the previous decade. Surprisingly, 37% of foresters from the Atlantic Coast states expected the rate of development to decrease over the next decade, while only 20% expected it to increase. In the Gulf Coast and Interior states, a greater percentage of foresters expected an increase in development than a decrease.

Not surprisingly, 90% of respondents reported an increase in the amount of forestland owned by TIMOs and REITs (Table 2.6). Fifty-seven percent of respondents reported that the TIMOs and REITs are more likely to convert forestland to development than the vertically integrated forest products companies from whom they purchased the land. In contrast, only 5% of respondents believed that TIMOs and REITs are less likely to convert tracts to development. In addition, 53% of respondents reported that TIMOs and REITs spend less money per hectare

Table 2.6: Trends in forest ownership, real estate development, and intensity of forest management according to consulting foresters from the southern states. Responses are reported as the percentage of respondents who gave a particular answer.

Question/Statement	Atlantic Coast	Gulf Coast	Interior	Overall
Have you noticed a shift towards real estate development in areas previously managed for timber production? (percent)				
Yes	91	80	79	85
No	8	16	21	13
Not Sure	1	4	0	2
How do you expect the rate of conversion from forestland to development to change in the next decade compared to the previous decade? (percent)				
Greater rate of conversion	20	30	28	25
About the same rate of conversion	43	48	58	48
Lesser rate of conversion	37	22	14	28
Have you seen an increase in the amount of land owned by timberland investment management organizations (TIMOs) and real estate investment trusts (REITs)? (percent)				
Yes	91	95	79	90
No	9	5	21	10
In your opinion, are TIMOs and REITs more or less likely to convert forestland to development than vertically integrated forest industry companies? (percent)				
TIMOs and REITs more likely to develop	53	71	41	57
TIMOs and REITs equally likely to develop	45	24	48	38
TIMOs and REITs less likely to develop	3	5	10	5
In your opinion, do TIMOs and REITs invest more or less money per acre on silvicultural treatments (fertilization, thinning, site preparation, etc.) than vertically integrated forest industry companies did? (percent)				
TIMOs and REITs spend more money	9	13	10	11
TIMOs and REITs spend same amount	36	35	38	36
TIMOs and REITs spend less money	55	52	52	53

on silvicultural treatments than the forest products industry companies did. Converting forestland to development and reducing investments in silviculture could lead to a long term decline in timber supply. Nonetheless, to date, timber supply has outpaced demand (Wear et al., 2007).

2.5.4 Harvesting Contractors

Fifty-three percent of respondents reported that the loggers in their area are reducing the size of their operations while only 7% of respondents reported that loggers are increasing the size of their operations. Forty-eight percent of respondents reported that there is an adequate number of loggers in their area. Twenty-eight percent reported that there are not enough loggers, while 24% reported that there are too many loggers in their area for the amount of timber available for harvest.

Despite the fact that most respondents did not believe there is a surplus of loggers, 92% of respondents reported that loggers in their area are “frequently” placed on quotas. Only 8% of respondents reported the frequency of loggers being placed on quotas as “seldom,” and no respondents reported that loggers in their area are “never” placed on quotas.

Greene et al. (2004) documented a history of excess logging capacity in the South, and our findings of loggers downsizing and mills frequently placing loggers on quotas also suggest excess capacity. However, this study was conducted during the summer of 2009 when southern timber markets were severely depressed and this is likely to have contributed to the apparent excess logging capacity. Only 24% of respondents reported that there are too many loggers for the amount of timber available for harvest, which further suggests that the apparent excess capacity may be due to the prevailing economic conditions at the time of the study. In addition, an aging logging workforce and a lack of recruitment of young owners (Baker and Greene, 2008) suggests that when traditional timber markets rebound and if a robust wood-energy market

develops there could be a shortage of harvesting contractors. Furthermore, if tight credit markets prevail after the recession this may create a barrier to entry for new logging contractors and may prevent loggers from purchasing the equipment necessary to deliver wood to energy facilities.

2.6 Conclusion

The findings of this study suggest that the southern wood supply chain is in position to take advantage of a wood-energy market. Nearly all respondents reported that their clients are willing to sell timber to energy facilities, and no respondents reported that their clients would not sell to an energy facility. Secondly, nearly all foresters in this study reported that they do not have adequate markets for timber. This indicates that there is timber available for producing energy and that an expanded energy market would not have a severe impact on the forest products industry. The consulting foresters in this study did expect competition between the forest products and wood-energy industries to raise stumpage prices, but not enough to displace traditional industries.

In order for the forest products and wood-energy industries to be successful they require harvesting contractors to harvest and deliver wood to their facilities. The long term outlook for southern logging capacity is unclear. The southern wood supply chain has a history of excess logging capacity (Greene et al., 2004), and during the summer of 2009 the presence of frequent mill quotas suggests excess capacity was still a problem, probably due to a severe US recession. In the long term, once the US economy recovers from a deep recession, wood demand from mills recovers, and wood-energy markets develop, the demand for wood will increase. However, an aging logging workforce and tight credit markets may make it difficult for loggers to respond to increased demand.

Three additional areas of concern for the southern wood supply chain include: increasing urbanization, decreasing harvest tract size, and changes in forest management associated with new forest ownership. This study found that the average harvest tract size has decreased during the past decade across the southeast and foresters expect a further decline over the next decade. Foresters reported that TIMOs and REITs are more likely to convert forestland to development than forest products companies and generally spend less money per hectare on silvicultural treatments than vertically integrated forest products companies, which indicates an eventual decline in timber availability if increases in forest productivity and afforestation fail to offset development activities.

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3.0 WOOD-ENERGY MARKET IMPACT ON COMPETITION, PROCUREMENT PRACTICES, AND PROFITABILITY OF LANDOWNERS AND FOREST PRODUCTS INDUSTRY IN THE U.S. SOUTH

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3.1 Abstract

Recent emphasis on producing energy from woody biomass has raised questions about the impact of an expanded wood-energy market on the U.S. South's wood supply chain. We conducted a survey of wood-energy facilities, fibermills, sawmills, private landowners, and government landholders to investigate the expected impact of a vibrant wood-energy market on the southern wood supply chain. Specifically, our study was designed to document potential competition for resources, wood supply chain profitability, and landowner willingness to sell timber to energy facilities. Results indicate that wood-energy facilities and traditional mills were not competing for raw material on a large scale at the time of the study, but competition is expected over the next decade. Almost 90% of fibermills reported that traditional forest industry mills should enter the wood-energy market, but most were skeptical that the new market would improve profitability. Ninety percent of responding landowners reported a willingness to sell timber to an energy facility if the right price is offered and all of those who had already sold timber to an energy facility were satisfied with the experience. Only 3.5% of respondents were unwilling to sell timber to an energy company, and only one of these respondents listed timber production as his primary objective, which indicates those who would not harvest timber for

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energy, may be unlikely to harvest timber for other purposes as well. This study suggests that the southern wood supply chain is in position to profit from a wood-energy market; however, concerns remain about the coexistence of the forest products and wood-energy industries.

3.2 Introduction

The wood-energy market represents an opportunity to produce electricity, heat, and transportation fuels from a renewable resource, while simultaneously stimulating rural economies, and promoting energy security [1,2,3]. As a consequence, federal and state governments have introduced incentives and subsidies to encourage energy production from wood and other renewable resources [4,5,6]. The U.S. has the potential to sustainably produce up to 334 million dry tonnes of wood each year which could be used for energy production [7]. In the U.S. South, Walsh et al. [8] estimated there are at least 19 million dry tonnes of woody biomass available for energy production, enough to generate 20 million megawatts of electricity [9], or 6.8 billion liters (1.8 billion US gal) of cellulosic ethanol [10].

The traditional southern wood supply chain, which consists of landowners, harvesting contractors, and processing facilities [11], is responsible for producing 60% of the nation's timber [12]. Forest-based industry employs over 700,000 people in the South, representing 1.3% of total southern employment [13]. Each link in the traditional wood supply chain has changed considerably over the last two decades. Average tract size has decreased on privately owned forestland [14,15,16], and the forest products industry has divested itself of much of its timberland [17]. Southern loggers have become more mechanized and more productive over the last 20 years; however, concerns over an aging workforce and lack of recruitment cloud the future of the profession [18,19]. Finally, the forest products industry has struggled in recent years losing 30% of its sawmills and 17% of its pulp and paper mills since the mid-1990s [20]. The

number of operational sawmills in the South has been declining for at least three decades and the number of pulpmills peaked at 116 in 1980 and has declined since, with 87 still operational in 2005 [20]. Sawtimber production increased by 6% between 1995 and 2005 [21], which suggests that surviving mills were able to expand capacity and take advantage of economies of scale. In contrast, pulpwood production declined by 15% between 1997 and 2006 [22].

There is concern among some in the traditional southern wood supply chain, especially in the pulp and paper industry, that a vibrant wood-energy market will result in subsidized competition for raw material. Past studies suggest that there is a level of wood-energy demand at which energy facilities must compete with traditional mills for wood. Perlack et al. [7] acknowledged that high oil prices and low timber prices could make pulpwood and other small diameter material available for energy production while others suggest that using pulpwood for energy is unlikely without a significant decline in the pulp and paper industry [23]. In Sweden, a bioenergy production threshold exists beyond which it becomes cheaper to utilize roundwood for energy rather than harvesting residues [24]. Likewise, Benjamin et al. [25] suggested that because wood suitable for use in pulp and paper facilities is also suitable for use in bioenergy facilities, the potential exists for bioenergy plants to compete with the pulp and paper industry for feedstock. Galik et al. [26] found that in North Carolina, South Carolina, and Virginia if the quantity of wood demanded by energy companies exceeds the availability of forest residues there will be a sharp increase in prices, which will displace marginal pulpwood consumers. Lastly, Conrad and Bolding [27] found that state regulatory mechanisms and the lack of biofuel refineries are likely to prevent competition in Virginia, at least in the near term.

The purpose of this study was to determine the expected impact of a vibrant wood-energy market on southern forest landowners and mills. Because of the potential benefits of wood-based

energy and the importance of the forest products industry to the southern economy, it is important to understand how a wood-energy market may impact landowners as well as the forest products industry. Therefore, our objectives were to: 1) examine the expected impact of a vibrant wood-energy market on stumpage prices and procurement practices, 2) examine the expected impact of a wood-energy market on the profitability of landowners and the forest products industry, 3) examine the attitudes of landowners and forest industry personnel toward government policies encouraging wood-based energy, and 4) examine landowners' expectations for wood-based energy and evaluate their willingness to sell timber to energy facilities.

3.3 Methods

A mail survey of forest landowners, forest products industry mills, and wood-energy facilities was conducted in order to investigate the expected impact of a vibrant wood-energy market on southern forest owners and mills. The U.S. South was defined as the states representing the USDA Forest Service Southern Region [28]. The Southern region includes: Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia.

The survey of landowners consisted of 268 family forest landowners, 53 institutional owners (banks, TIMOs, REITs, etc.), and 26 state and federal government officials. Family and institutional participants were selected with cooperation from the Forest Landowners Association. Members of the Forest Landowners Association tend to own larger tracts of timber and actively manage their land more so than typical southern family forest landowners, meaning their responses are not necessarily representative of the majority of southern forest landowners. However, members of the Forest Landowners Association should represent the views of southern

landowners who actively manage their land and will play a major role in supplying the forest products and wood-energy industries with wood.

Twenty-one family forest owners were sampled in each state with the exceptions of Oklahoma and Texas which had 17 and 20 participants, respectively. Family forest landowners were stratified by state and a random number generator [29] was used to randomly select landowners within each state. Many institutional owners completed their questionnaire as an individual owner, and therefore institutional owners and family forest landowners were concatenated into “private landowners” for analysis. The state forester from each state and the forest supervisor of the national forests in each state represented government landholders in the survey.

The survey of mills was divided into sawmills and fibermills [30]. Sawmills included both sawmills and plywood/veneer mills. Fibermills included pulp and paper mills as well as composite mills (OSB, particleboard, etc.). Mills were identified using forest products industry directories published by individual states as well as Prestemon et al. [31]. Sawmills were stratified by state and a random number generator [29] was used to randomly select sawmills within each state. A total of 240 sawmills were sampled. Twenty sawmills were sampled from each state, with the exceptions of Alabama and Georgia which had nineteen each, as well as Florida and Oklahoma which had twelve and ten representatives, respectively. All 127 fibermills listed in the directories were included in the survey.

Twenty-nine wood-energy facilities were included in the survey. Fifteen wood pellet mills were identified from the list maintained by the Pellet Fuels Institute [32]. Fourteen wood-using power plants were selected by contacting state regulators and requesting a list of facilities permitted to burn wood to produce electricity.

The survey consisted of five mailings designed according to the Tailored Design Method [33]. The mailing sequence began with a prenotice letter during the second week of July, 2009, followed by a questionnaire with a personalized cover letter four days later. Approximately two weeks after the questionnaire was mailed, a reminder postcard was sent. Four weeks after the postcard, a second questionnaire and cover letter were mailed to non-respondents. Finally, two weeks after the second questionnaire mailing, a second postcard was mailed to non-respondents. A bookmark was included along with the first questionnaire as a token of appreciation for participating in the survey and respondents were also offered a copy of the results as an additional incentive for participating.

This study utilized two questionnaires: one for landowners and another for mills and energy facilities. Separate questionnaires allowed for the collection of information specific to landowners, mills, and energy facilities. The two questionnaires had eight common questions which enabled us to make comparisons across all populations of interest. Each questionnaire consisted of thirty closed-ended questions. The questionnaires were limited to one page front and back to reduce the effort required to respond and thus increase the response rate [34]. The questionnaire sent to mills and energy facilities contained fourteen likert scale question (5 and 7-point scales), four questions requested numerical responses, and the remaining twelve questions requested nominal data. The landowner questionnaire contained sixteen likert scale questions (7-point scale), three questions requested numerical responses, and the remainder requested nominal data.

Likert scale questions were analyzed using the Tukey HSD test to determine if the mean response was significantly different between populations. The two-tailed t-test assuming unequal variance was used to compare mean responses when only two populations were being compared.

One-tailed t-tests were conducted to test the null hypothesis that a response was significantly different from neutral. Logistic regression was used to determine the odds that one population would agree vs. not agree with a particular statement. The odds were then compared using an odds ratio. The odds ratio demonstrates how much more likely a population is to agree with a statement compared to another population. The chi-square test of independence was used to test nominal survey data as well as likert scale questions which were rescaled into “agree” and “not agree” categories. All statistical analysis was conducted at the $\alpha = 0.05$ level and statistical analysis was performed using JMP statistical software [35] and Excel spreadsheets [29].

Nonresponse bias was assessed using wave analysis [36], which compared early respondents to late respondents. The responses received after the first mailing were compared to the responses received after the second mailing on four questions. Nonresponse bias was only assessed for private landowners, fibermills, and sawmills because of the small sample sizes for the other populations. The chi-square test of independence was used to test nonresponse bias.

3.4 Results and Discussion

Eighty-seven questionnaires could not be delivered, which reduced our sample size to 656. A total of 307 questionnaires were returned, of which 301 were usable, which yielded an adjusted response rate of 46%. The adjusted response rates by population were 31% for sawmills, 36% for fibermills, 46% for wood-energy facilities, 59% for private landowners, and 65% for government landholders. No statistically significant differences were observed between early and late respondents, which suggests that nonresponse bias was not a major source of error in this study.

3.4.1 Competition for Raw Material

The forest products industry is the primary market for timber at present, and most competition for resources occurs between traditional mills; however, over the next ten years it is expected that wood-energy facilities will compete with traditional mills. Ninety-five percent of responding fibermills and 97% of sawmills reported that their biggest competitor today is a traditional forest products industry facility. Likewise, 55% of wood-energy facilities counted fibermills as their largest competitor today versus only 45% who counted another energy facility as their biggest competitor.

Thirty-two percent of fibermills expected that a wood-fired power plant will be their largest competitor in ten years and another five percent believed that a pellet mill will be their largest competitor. Similarly, 78% of wood-energy facilities expected another energy facility to be their top competitor in ten years while only 22% expected a fibermill to be their biggest competitor. Only ten percent of sawmills expected their largest competitor to be a wood-energy facility in ten years. The change in expected competitors from 2009-2019 was statistically significant for fibermills ($\chi^2 = 12.061$; $P < 0.01$).

A majority of mills and energy facilities reported increases in raw material costs over the past ten years (Table 3.1). The primary reason for this increase, according to sawmills and fibermills, was competition between mills. Over the next decade, a majority of mills and energy facilities expected wood costs to increase further. Seventy percent of fibermills expected raw material costs to increase because of competition between mills and energy facilities. The change in the number of fibermills that credit competition between energy facilities and mills with an increase in fiber costs between 1999 and 2019 was significant ($\chi^2 = 30.585$; $P < 0.01$).

Table 3.1: Trends in raw material costs for energy facilities, fibermills, and sawmills from 1999 to 2019 and the reported reasons for these trends. The chi-square test of independence was used to test the hypothesis that the same proportion of respondents from each population experienced or expects to experience an increase in wood prices versus the alternative that the proportion was not the same for each population. Mean response refers to the average response on a 5-point likert scale question (1 = increased significantly; 2 = increased somewhat; 3 = neither increased nor decreased; 4 = decreased somewhat; 5 = decreased significantly). Mean responses not connected by the same letter are significantly different at the $\alpha = 0.05$ level.

Question/Statement	Wood-Energy	Fibermills	Sawmills
How did the average price you paid for wood change <i>over the last ten years?</i> (%) ($\chi^2 = 13.8$; $P < 0.01$)			
Increased	90	89	58
Remained Constant	0	3	3
Decreased	0	8	39
Not Sure	10	0	0
Mean Response	1.44 ^a	1.86 ^a	2.67 ^b
Which of the following played the largest role in the price you paid for wood over the <i>last ten years?</i> (%)			
Competition between mills	17	57	59
Competition between mills and energy facilities	17	11	5
Health of U.S. Economy	50	8	28
Changes in forest ownership/tract size	0	19	5
Other	17	5	3
How do you expect the price you pay for wood to change <i>over the next decade?</i> (%) ($\chi^2 = 12.2$; $P < 0.01$)			
Increase	82	100	73
Remain Constant	0	0	6
Decrease	0	0	3
Not Sure	18	0	18
Mean Response	1.78 ^a	1.62 ^a	1.89 ^a
Which of the following do you expect to play the largest role in the price you pay for wood over the <i>next ten years?</i> (%)			
Competition between mills	0	14	35
Competition between mills and energy facilities	50	70	18
Health of U.S. Economy	40	11	25
Other	10	5	22

Fibermills appear to be more concerned about competition for resources than any other group. Energy facilities were eight percent as likely as fibermills to expect competition between energy facilities and mills, meaning that fibermills were 12.5 times (reciprocal of odds ratio) more likely to expect competition (Table 3.2). All responding fibermills expected future competition for resources to increase stumpage prices and the mean response from fibermills was significantly different from all other groups. Fibermills were also the most likely to believe that energy facilities will have an advantage in procuring wood.

Our finding that fibermills were most concerned about competition for resources comes as no surprise. The southern pulp and paper industry is already struggling with aging mills, many of which are no longer competitive with foreign mills. Consequently, the U.S. South lost twenty-nine pulp and paper facilities between 1980 and 2005 and continues to experience closures [20]. Additionally, as the wood-energy industry grows, competition for wood is expected to begin with low-value or non-commercial wood and progress to higher grades of timber as demand increases [37]. Pulpwood is commonly the lowest grade of timber and therefore will be the first to face competitive pressures if energy demand exceeds the availability of non-commercial fiber. In the first quarter of 2010 the delivered price of whole tree chips was approximately \$23 per tonne, compared to \$31-\$33, \$36, and \$44+ per tonne for pulpwood, chip-n-saw, and pine and hardwood sawtimber, respectively [38]. Energywood prices would have to increase by 50% in order to compete with chip-n-saw and would have to increase by nearly 100% to compete with sawtimber, which appears unlikely. However, demand from energy companies is often driven by government policies and regulations rather than market forces [37], and government programs such as the Biomass Crop Assistance Program (BCAP) have the potential to change the economics of wood procurement [39]. For example, Conrad and Bolding [27] found that

Virginia incentives would give biofuel manufacturers a \$4.50 per tonne advantage (approximately 15% of the delivered price of pulpwood) over the forest products industry in procuring wood.

3.4.2 Wood Supply Chain Profitability

During 2009 the annual unemployment rate was 9.3% [40] and GDP declined by 2.4% [41]. The forest products industry was impacted to a greater extent than other industries because of the decline in the housing market. Therefore, it is not surprising that only 10% of responding sawmills and fibermills suggested forest industry mills are operating at an acceptable level of profitability. The mean response to this question was significantly different from neutral for both sawmills and fibermills ($P < 0.01$). Unfortunately, less than forty percent of sawmills and fibermills expected profitability to improve over the next decade.

Less than half of responding sawmills and fibermills expected traditional forest industry to become more profitable as a result of an expanded wood-energy market. However, 89% of fibermills and 58% of sawmills suggested that the traditional forest products industry could and should produce and sell energy from wood. The difference in the mean response between sawmills and fibermills was significant ($P < 0.05$), and the mean response to this question was significantly different from neutral for both groups ($P < 0.01$). Fifty-seven percent of fibermills suggested that traditional forest industry should partner with energy companies if they attempt to produce energy from wood, while only 27% of sawmills favored a partnership; although, a large percentage of respondents were unsure which endeavor would be most profitable.

Table 3.2: Stakeholder expectations regarding competition for resources between forest products industry mills and wood-energy facilities. The mean response is the average of the responses from each group on the 7-point likert scale question (1 = strongly agree; 4 = neutral; 7 =strongly disagree). Mean responses not connected by the same letter are significantly different at the $\alpha = 0.05$ level. The odds ratio compares the odds that wood-energy facilities, sawmills, private landowners, and government landholders would agree with a particular statement compared to the odds of a fibermill agreeing with the same statement.

Question/Statement	Agree (%)	Neutral (%)	Disagree (%)	Mean Response	Odds Ratio ^a
Wood-to-energy facilities will compete for wood with forest industry mills ($\chi^2 = 16.5$; $P < 0.01$)					
Wood-Energy	64	27	9	2.55 ^{abc}	0.08
Fibermills	95	5	0	1.54 ^a	reference
Sawmills	77	14	9	2.48 ^b	0.16
Private Landowners	69	20	11	2.65 ^b	0.13
Government Landholders	47	12	41	3.88 ^c	0.05
If competition occurs between wood-to-energy facilities and forest industry mills, it will cause stumpage prices to increase ($\chi^2 = 9.9$; $P = 0.04$)					
Wood-Energy	73	9	18	3.00 ^a	0.06
Fibermills	100	0	0	1.68 ^b	reference
Sawmills	80	11	9	2.40 ^a	0.11
Private Landowners	79	15	6	2.46 ^a	0.11
Government Landholders	76	24	0	2.82 ^a	0.09
If competition occurs, wood-to-energy facilities will have an advantage over forest industry mills in purchasing wood ($\chi^2 = 37.4$; $P < 0.01$)					
Wood-Energy	46	27	27	3.18 ^{ab}	0.30
Fibermills	70	19	11	2.43 ^a	reference
Sawmills	53	27	20	3.16 ^a	0.44
Private Landowners	28	27	45	4.05 ^{bc}	0.16
Government Landholders	6	41	53	4.88 ^c	0.03

^aThe odds ratio is calculated by dividing the odds that a facility representative would agree with a particular statement by the odds that a fibermill would agree with the same statement. The odds ratio should be interpreted as follows: energy facilities are 8% as likely as fibermills to agree with the first statement. Conversely, fibermills are 12.5 times (1/0.08) more likely than energy facilities to agree with the statement.

Seventy-six percent of private landowners and all government landholders reported that traditional forest industry mills are important to achieving their objectives. The mean response to this question was significantly different from neutral for both landowner types ($P < 0.01$). Similarly, 72% of private landowners responded that a decline in traditional forest industry mills makes their forestland investment less valuable. The mean response to this question was also significantly different from neutral ($P < 0.01$).

These results indicate that the forest products industry recognizes its need to improve profitability. The industry also recognizes the wood-energy market as an opportunity to supply an additional product to the marketplace, although they were somewhat skeptical of its impact on the bottom line. Both private and public landowners recognize the importance of the forest products industry in meeting their objectives.

3.4.3 Wood Procurement Practices

Responding mills and energy facilities consume wood in very different forms. As expected, sawmills use primarily roundwood (Table 3.3). Fibermills primarily use roundwood, mill residues, and clean chips. Wood-energy facilities use primarily mill residues and whole tree chips. The difference in the average and weighted average percentage of mill residues and whole tree chips used by energy facilities indicates that small facilities depend mostly on mill residues while larger facilities rely more heavily on whole tree chips. Energy facilities' lack of dependence on roundwood indicates that they are currently procuring wood without competing significantly with the forest products industry. Nonetheless, if the price of energywood approximated the price of pulpwood, harvesting contractors would have the option to chip pulpwood-sized trees for energy.

Table 3.3: Wood source for wood-energy facilities, fibermills, and sawmills in the U.S. South reported as the average and weighted average (in parentheses) percentage of total wood consumption for each facility type.

Wood Source	Wood-Energy	Fibermills	Sawmills
Roundwood (%)	<1 (1)	62 (63)	92 (88)
Clean Chips (%)	6 (6)	12 (17)	1 (<1)
Whole Tree Chips (%)	17 (33)	5 (5)	0 (0)
Harvesting Residues (%)	2 (6)	2 (2)	0 (0)
Urban Wood Waste (%)	6 (4)	1 (<1)	0 (0)
Mill Residues (%)	59 (38)	18 (13)	2 (2)
Other (%)	10 (12)	0 (0)	5 (9)

Sawmills procure a majority of their roundwood from wood dealers/loggers (46%), gatewood (25%), and stumpage purchases directly from landowners (22%). Fibermills get a larger percentage (60%) of their roundwood from wood dealers/loggers than do sawmills. Fibermills also get a significant amount of wood as gatewood (11%), direct stumpage purchases (11%), and chip mills (7%). Sawmills and fibermills procured only 7% and 5.5% of their roundwood from company land, respectively.

Altman and Johnson [42] found that energy companies utilize external wood procurement to supply their facilities while most other biopower producers have internal, vertically integrated

wood procurement systems. The energy companies typically used either spot markets or contracts which varied in length from several months up to twenty years. The forest products industry typically uses internal or a mixture of internal and external systems of boiler fuel procurement [42]. However, our study indicates that more than 90% of the wood which enters the gates of forest industry mills originates from outside the organization. Therefore, it should be concluded that both energy companies and the forest products industry must rely on outside sources of wood, either through spot markets or contracts.

Eighty-one percent of fibermills, 63% of wood-energy facilities, and 50% of sawmills expected procurement practices to change as a result of wood-energy expansion. Fibermills expected increases in wood yard inventories, long term wood supply agreements, and stumpage purchases directly from landowners (Table 3.4). Wood-energy facilities also expected increases in long term wood supply agreements and purchases from wood dealers. The anticipated expansion of wood supply agreements agrees with previous research which indicates biopower producers prefer contracts to spot markets [42].

3.4.4 Government Policies

More than 70% of all respondents expected government policies such as tax breaks, subsidies, targets, and mandates to play a significant role in determining what, if any, competition occurs between wood-energy facilities and the forest products industry. Only private landowners had less than 80% agreement on this item. A majority of fibermills opposed granting tax breaks and subsidies to wood-using energy companies while energy facilities and landowners tended to favor aid to the energy companies (Table 3.5). Fibermills overwhelmingly felt that tax breaks and subsidies will make mills less competitive in purchasing wood, although the other

groups were less certain. Similarly, fibermills had the lowest level of support for renewable electricity standards.

Table 3.4: Expected changes in wood procurement practices as reported by wood-energy facilities, fibermills, and sawmills from the U.S. South. Responses are reported as the percentage of respondents that gave a particular answer.

Practice	Increase (%)	Remain the same (%)	Decrease (%)
Purchases from wood dealers			
Wood-Energy	60	20	20
Fibermills	44	42	14
Sawmills	41	48	11
Stumpage purchases directly from landowners			
Wood-Energy	40	50	10
Fibermills	51	43	6
Sawmills	41	51	8
Gatewood purchases from loggers			
Wood-Energy	20	80	0
Fibermills	37	54	9
Sawmills	32	62	6
Long term wood supply agreements			
Wood-Energy	82	0	18
Fibermills	56	33	11
Sawmills	40	53	7
Inventory level in wood yard			
Wood-Energy	36	46	18
Fibermills	75	17	8
Sawmills	15	54	31

Table 3.5: Stakeholder attitudes towards government policies promoting wood-based energy.

Means not connected by the same letter are significantly different at the $\alpha = 0.05$ level. The odds ratio compares the odds that wood-energy facilities, sawmills, private landowners, and government landholders would agree with a particular statement compared to the odds of a fibermill agreeing with the same statement.

Question/Statement	Agree (%)	Neutral (%)	Disagree (%)	Mean Response	Odds Ratio ^a
I support tax breaks and subsidies for wood-using energy companies ($\chi^2 = 33.1$; $P < 0.01$)					
Wood-Energy	64	18	18	2.82 ^{ab}	11.55
Fibermills	13	19	68	5.30 ^c	reference
Sawmills	42	17	42	4.17 ^{ac}	5.92
Private Landowners	63	14	23	3.31 ^b	13.88
Government Landholders	50	36	14	3.57 ^{abc}	8.25
Tax breaks and subsidies given to wood-using energy companies will make forest industry mills less competitive in purchasing wood ($\chi^2 = 23.9$; $P < 0.01$)					
Wood-Energy	46	27	27	3.73 ^a	0.04
Fibermills	92	5	3	1.76 ^b	reference
Sawmills	51	29	20	3.18 ^a	0.05
Private Landowners	49	30	21	3.45 ^a	0.05
Government Landholders	50	38	12	3.44 ^a	0.06
I support renewable electricity standards which mandate utilities to produce a certain percentage of their electricity from renewable sources by a target date ($\chi^2 = 8.9$; $P = 0.06$)					
Wood-Energy	73	18	9	2.54 ^a	4.73
Fibermills	32	22	46	4.54 ^b	reference
Sawmills	41	25	34	4.09 ^{ab}	1.70
Private Landowners	51	20	29	3.66 ^{ab}	2.48
Government Landholders	60	27	13	3.33 ^{ab}	3.55

These results underscore the concerns of fibermills regarding competition for wood fiber. Hillring [37] found that wood fuel markets are often driven by government policies such as the Kyoto Protocol. This explains fibermills opposition to government policies promoting wood-based energy.

3.4.5 Landowner Expectations

Private landowners own nearly 90% of southern forestland [43]. The median holding size of private landowners in this study was 216 ha, and 170 ha for family forest owners, which is considerably larger than the median of less than four ha for all family forest owners. In addition, 88% of respondents reported harvesting timber over the past decade compared to 46% of family forest owners nationwide [43]. Similarly, 60% of respondents listed investment/timber production as their primary reason for owning timberland, which is a considerably larger percentage compared to American forest landowners as a whole. Therefore, respondents should represent landowners who actively manage their land and are relied upon to sell wood to both energy facilities and mills.

Only 12% of private landowners and 6% of government landholders reported having sold wood to an energy facility; however, all of those who had sold to an energy facility were satisfied with the experience. This is encouraging considering that Bohlin and Roos [44] found strong dissatisfaction among some Swedish landowners who sold timber to an energy facility. Ninety percent of private and public landowners reported that they are willing to sell timber to an energy facility if the right price is offered. The mean response to this question was significantly different from neutral for both landowner types ($P < 0.01$). However, only 55% and 25% of private and public landowners would harvest timber more often as a result of a wood-energy market, suggesting that landowners would sell timber to energy facilities primarily as a means of

increasing revenue from already planned harvests. Only 25% of private landowners and approximately half of public owners reported that their loggers chip non-merchantable stems and residues. This indicates loggers may have to invest in different equipment if a vibrant wood-energy market emerges.

Over 90% of respondents planned to regenerate their stands following timber harvest, which should help to ensure a long term source of wood for both the forest products and wood-energy industries. Approximately one-third of respondents would be willing to convert some of their forestland to energy crops such as switchgrass if a vibrant bioenergy market emerges.

Two-thirds of private landowners reported that a vibrant wood-energy market would make them less likely to convert their land to another use and 58% will be more likely to regenerate their forests after harvest as a result of a wood-energy market. Both responses were significantly different from neutral ($P < 0.05$). Two-thirds of private landowners would be more likely to invest in intermediate treatments as a result of a vibrant wood-energy market, but only half of private landowners believed the health of their forestland will improve as a result of a wood-energy market. In contrast, 75% of government landholders suggested forest health will improve as a result of an expanded wood-energy market.

3.5 Summary and Conclusions

Results of this study confirm that fibermills, both the pulp and paper and composite sectors, are concerned about competition for resources with wood-energy facilities. As a result, fibermills are opposed to many government policies encouraging wood-based energy. At present, wood-energy facilities procure the majority of their wood from mill residues and whole tree chips and are not competing for raw material in roundwood form (Table 3.3).

The majority of respondents suggested that the traditional forest products industry is in position to produce energy from wood. The forest products industry is in ideal position to take advantage of the burgeoning wood-energy market as the industry already has a wood supply chain in place and owns a majority of the cogeneration capacity in the United States [45]. Furthermore, with the pulp and paper industry struggling to stay competitive globally, producing energy could provide an additional market and help the sector remain competitive while also achieving the societal desire for renewable energy.

Our findings suggest that major stakeholders expect the wood-energy market to have a significant impact on the southern wood supply chain. While fibermills are concerned about the potential for competition – particularly subsidized competition – they also see an opportunity to benefit from the new market by producing energy in addition to traditional forest products. Landowners stand ready to supply wood to a new market, but also recognize the importance of a strong forest products industry. Therefore, this study suggests that a wood-energy market should benefit the southern wood supply chain. However, additional research is needed to: 1) quantify the amount of realistically available (versus potentially available) woody biomass, 2) identify supply chain bottlenecks in delivering woody biomass in a cost-effective manner, and 3) determine the impact of specific bioenergy policies on the forest products industry.

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4.0 HARVESTING PRODUCTIVITY AND COSTS WHEN UTILIZING ENERGYWOOD FROM PINE PLANTATIONS OF THE SOUTHERN COASTAL PLAIN USA

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4.1 Abstract

In order for woody biomass to make significant contributions to the United States' energy portfolio, harvesting contractors must be able to economically harvest and transport energywood to conversion/processing facilities. We conducted a designed, operational study on a southern pine clearcut in the Coastal Plain of North Carolina, USA with three replications of three harvest treatments to measure harvesting productivity and costs when utilizing woody biomass for energy. The three treatments were: a Conventional roundwood only harvest (control), an Integrated harvest in which merchantable roundwood was delivered to traditional mills and residuals were chipped for energy, and a Chip harvest in which all stems were chipped for energy use. The harvesting contractor in this study typically delivers between 2,200 and 2,700 green t of roundwood per week, and is capable of wet-site harvesting. Results indicate that onboard truck roundwood costs increased from \$9.35 green t⁻¹ in the Conventional treatment to \$10.98 green t⁻¹ in the Integrated treatment as a result of reduced felling and skidding productivity. Energy chips were produced for \$19.19 green t⁻¹ onboard truck in the Integrated treatment and \$17.93 green t⁻¹ in the Chip treatment. Low skidding productivity due to small stems contributed to the high chip costs in the Integrated treatment. Residual woody biomass was

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reduced from 18 green t ha⁻¹ in the Conventional treatment to 4 and 3 green t ha⁻¹ in the Integrated and Chip treatments, respectively. This study suggests that until energywood prices appreciate substantially, loggers are unlikely to sacrifice roundwood production to increase energywood production. This research provides unique information from a designed experiment documenting how producing energywood affects each function of a harvesting system.

4.2 Introduction

In recent years, concerns about America's dependence on fossil fuels and sustainability have led to increased interest in producing energy from renewable sources such as woody biomass [1,2,3]. Past research suggests there are sufficient forest resources available to support an expanded wood-energy industry [4,5,6]. As a result, state and federal governments have developed incentives and regulatory measures that promote renewable energy, including energy from woody biomass. For example, the Energy Independence and Security Act of 2007 requires that 136 billion liters of renewable fuels be produced by 2022, of which 79 billion liters must be produced from advanced biofuels such as cellulosic ethanol [7]. The Biomass Crop Assistance Program (BCAP) was designed to provide financial assistance for the harvest and transportation of eligible biomass to conversion facilities. However, this program had the unintended consequence of raising wood prices for traditional wood users such as the composite panel and pulp and paper industries [8]. Thirty-six states have enacted renewable portfolio standards or goals that mandate or set goals for utilities to produce a certain amount or percentage of electricity from renewable sources by a target date [9]. The U.S. South has been less proactive in terms of both renewable portfolio standards and incentives for renewable energy than other states [10]; nonetheless, each southern state has at least one policy promoting bioenergy [3].

Wood that is used to produce energy is derived from one of three sources: 1) wood that is currently not used (i.e. harvesting residues, noncommercial stems, etc.) [6,11], 2) wood from dedicated bioenergy plantations [1,12], or 3) wood that is currently used for another purpose (i.e. traditional products such as pulpwood) [5,13]. Harvesting residues have the advantage of being commonly available with few or no modifications to silvicultural practices; however, these residues may be prohibitively expensive to process and transport in some areas [14,15], and may not be available in sufficient quantities to meet some government renewable energy goals/mandates [16,17]. Hardwood bioenergy plantations are of interest because hardwoods have better physical attributes for producing energy than pine [12,18]. However, pine plantations have lower establishment costs and can be productive on a wider range of sites than hardwood plantations [12].

Past research indicates that a substantial expansion of the wood-energy market may create competition between the forest products and wood-energy industries [16,19,20]. Galik et al. [16] suggested that wood-energy demand exceeding the availability of harvesting residues could cause a sudden increase in roundwood prices, which could displace some current wood users. To date, no such competition has been documented at the state level. For example, Virginia has a wood-energy market that is comparable in size to other southern states [21]. It has an 80 megawatt wood-fired power plant, seven wood pellet producers [22], and a bioenergy combined heat and power electricity capacity of 2,280 gigawatts [21]. However, Virginia has experienced minimal competition between the forest products and wood-energy industries [23], and most of the loggers harvesting energywood in the state are concentrated around a single market [24]. Virginia did lose one of its largest paper mills in 2010; however, this closing was a result of reduced paper demand, not competition from the wood-energy industry [25].

Nonetheless, Conrad et al. [19,20] found that a majority of consulting foresters, wood-energy facilities, pulp and paper mills, composite mills, sawmills, and private landowners surveyed in the U.S. South expected wood-energy facilities and forest industry mills to compete for wood in the future. If these expectations come to fruition, landowners and harvesting contractors may decide whether to sell pulpwood-sized material to a paper mill or to an energy facility. This decision may take the form of selling roundwood pulpwood to a paper mill vs. chipping the pulpwood and selling it to a wood-fired power plant for energy production.

When deciding between selling roundwood pulpwood or energy chips, landowners and loggers should consider the harvesting costs associated with the two products. For example, if energy chips can be produced for \$1 green t⁻¹ less than roundwood pulpwood, then the market price of roundwood pulpwood must exceed the market price of energy chips by at least \$1 green t⁻¹ in order for the landowner or logger to be indifferent between selling the two products. Past research investigating the cost of producing energywood has assumed that roundwood pulpwood would be of higher value than energy chips, and therefore did not estimate the cost of chipping this material. Research by Westbrook et al. [26] in the Coastal Plain of Georgia suggested that chips could be produced from limbs and tops for \$12 green t⁻¹, while chips can be produced from limbs, tops, and understory stems for \$13 green t⁻¹. Research in the Coastal Plain and Piedmont of Georgia by Baker et al. [27] found that energy chips could be produced for between \$8.67 and \$14.44 green t⁻¹ in clearcuts, depending on the harvest treatment, while roundwood production costs in these harvests varied between \$8.04 and \$9.36 green t⁻¹. In thinnings, harvesting costs varied between \$11.15 and \$15.48 green t⁻¹ while chipping costs varied between \$8.63 and \$10.59 green t⁻¹. In addition, adding a chipper to a traditional southern pine harvesting operation reduced roundwood production during thinning.

It is critical that harvesting costs be taken into account when determining the viability of wood-energy projects. Accurate estimates of energywood harvesting costs also enable harvesting contractors to make informed decisions about purchasing equipment. The overall purpose of this study was to investigate harvesting productivity and costs under three harvest prescriptions in the Coastal Plain. The specific objectives were to: 1) quantify the difference in roundwood harvesting costs between harvesting roundwood only and integrating roundwood and energy chip production, 2) quantify the difference in hourly production rates and energy chip harvesting costs for stand-alone energywood production versus integrated roundwood and energy chip production, 3) investigate whether adding a chipper to a tree-length southern pine harvesting operation reduces hourly and per ha roundwood production, 4) compare woody biomass utilization between roundwood only harvesting, energy chip harvesting, and integrated roundwood and energy chip harvesting, and 5) compare energy chip harvesting costs with high-production, wet-site capable loggers to past research that employed loggers with smaller capital investments.

4.3 Methods

4.3.1 Harvest Prescriptions and Site Description

Three replications of three harvest prescriptions (9 experimental units) were conducted in the Coastal Plain of North Carolina arranged as a randomized complete block design [28]. The three harvest treatments were:

- **Conventional:** A roundwood only tree length southern pine commercial clearcut. In this treatment, sawtimber, chip-n-saw, and roundwood pulpwood were harvested and transported to sawmills, chip-n-saw mills, and paper mills. This treatment is typical of harvests in the Coastal Plain [24] and served as a control.

- Integrated: An integrated roundwood and fuel chip clearcut in which both merchantable and non-merchantable stems were felled. Stems were separated by the feller-buncher, with the merchantable ones skidded to a loader to be processed as roundwood and the non-merchantable stems skidded to a chipper. Merchantable stems were defined as those ≥ 10 cm in diameter at breast height (dbh) and non-merchantable stems were defined as those < 10 cm dbh.

Merchantable roundwood was processed as in the Conventional treatment and delivered to appropriate mills while limbs, tops, and non-merchantable stems were chipped and delivered to a paper mill for use as boiler fuel.

- Chip: An energy chip harvest in which merchantable and non-merchantable stems were felled and skidded together to a chipper. All stems in this treatment were chipped as whole trees and delivered to a paper mill for use as boiler fuel. The purpose of this treatment was to simulate the circumstance in which the price of energy chips and roundwood pulpwood is approximately equal, and landowners and harvesting contractors may choose between delivering roundwood pulpwood to a pulpmill or delivering dirty chips to an energy facility.

This study was conducted during the summer of 2010 in Bertie County, North Carolina on a 51.1 ha loblolly pine (*Pinus taeda* L.) plantation. The site is located in the lower Coastal Plain and is part of the Roanoke River basin. The site is considered to be a wet pine flat with slopes of less than 2%. Soil series are primarily Leaf loams and Lenoir fine sandy loams, both of which are aquults [29]. These soils are classified as poorly to somewhat poorly drained. The plantation was established by Champion International Corporation during the 1980s, and is currently managed by Forest Investment Associates.

The plantation was divided into three blocks and a complete set of treatments (3) were applied to each block, yielding 9 experimental units. The Conventional and Chip treatments were

switched from their random assignments in Blocks 2 and 3 at the behest of the forest manager for logistical reasons. However, this change was determined not to have biased the study, and therefore the results were analyzed as a randomized complete block design. The blocks were arranged so that average skid distance was approximately equal for each treatment within a block, but skid distance varied between blocks (Table 4.1). The size and age of the three blocks and nine harvest units are given in Table 4.1.

Table 4.1: Harvest area (ha) within each experimental unit (treatment), total area within each block, age (yrs.) of each experimental unit, and average skid distance (m) within each experimental unit and block, and age of each experimental unit.

Block	Treatment	ha	Average Skid Distance (m)	Age (yrs.)
Block 1				
	Conventional	6.7	335	22
	Integrated	7.9	365	22
	Chip	4	335	22
	Total	18.6	345	
Block 2				
	Conventional	6.7	245	26
	Integrated	5	275	22/26
	Chip	4	260	22/26
	Total	15.7	260	
Block 3				
	Conventional	6.2	290	22
	Integrated	5.9	275	22/26
	Chip	4.7	290	22
	Total	16.8	285	

One fixed radius plot per 0.4 ha was sampled in each block to estimate standing biomass prior to harvest. Merchantable stems ≥ 10 cm in diameter at breast height (dbh) were sampled using 0.04 ha plots in Blocks 2 and 3 and 0.02 ha plots in Block 1. Smaller plots were used in Block 1 due to greater stand density. Non-merchantable stems (< 10 cm dbh) were measured using 0.0004 ha plots. For merchantable pine stems (≥ 10 cm dbh), species, dbh, and total height were recorded for each sampled tree. For merchantable hardwood stems (≥ 10 cm dbh), species and dbh were measured for each tree at each plot, while total height was measured at every third plot, with the remaining heights estimated using simple linear regression. For non-merchantable stems (< 10 cm dbh), species and dbh were recorded for each stem within each plot, with the exception of cane (*Arundinaria gigantea* L.) for which the number of stems were simply tallied. Stem weights were estimated using published equations [30,31,32,33,34].

Following harvest, five fixed radius plots per ha were sampled to estimate residual biomass in each harvest unit. Standing trees ≥ 7.6 cm dbh were sampled using 0.04 ha plots. Stems smaller than 7.6 cm dbh were sampled using 0.0004 ha plots and down logs were sampled using 0.008 ha plots. For standing trees, dbh, species, and total height were measured. For down logs, small-end diameter, large-end diameter, and length of the log within the plot were measured for logs with a large-end diameter ≥ 5 cm and a minimum length of 0.3 m. Weights of standing trees were estimated using published equations [30,31,32]. Weights of down logs were estimated by determining volume using the equation of a cone and multiplying this value by previously published weight per unit volume values [30,35].

4.3.2 Equipment Mix and Cost Assumptions

The harvesting contractor observed in this study typically delivers between 2,200 and 2,700 green t of roundwood per week. The logger's equipment mix includes: one Tigercat 822C

tracked feller-buncher, one Tigercat 625C grapple skidder with dual tires, one Tigercat E620C grapple skidder with dual tires, one Tigercat 250 tracked loader, one Tigercat 240B tracked loader, two CSI 3000 self-contained remote controlled pull-through delimiters, two CSI 4400 bucksaws, a Conehead 580 drum chipper, and a Tigercat 845 harvester that had been rebuilt to function as a shovel. Both loaders simultaneously processed wood and loaded trucks. The shovel fed the chipper in the Integrated and Chip treatments, but served no function in the harvesting of roundwood.

Equipment costs were estimated using the machine rate method [36]. For each machine we assumed a salvage value of 20% of the purchase price, economic life of 5 years, interest rate of 8% of average yearly investment, 2000 scheduled machine hours (smh) per year, and a lube rate of 40% of fuel consumption [37]. Utilization for the delimiters, buck saws, and chipper were estimated using activity samples taken during the study [38]. Fuel consumption for the chipper was estimated using data collected during the study. The average wage rate for logging equipment operators in North Carolina of \$13.92 per hour [39] was assumed for all equipment operators. Labor overhead was estimated to be 40% of the base rate [40]. Cost assumptions that varied by machine are listed in Table 4.2.

Harvesting costs (US\$ green t⁻¹) were estimated by combining productivity estimates with machine costs in the Auburn Harvesting Analyzer (AHA) [41]. For the Conventional treatment the costs of the following equipment were included in the AHA: one feller-buncher, two skidders, two delimiters, two bucksaws, and two loaders. For the Integrated treatment the costs of one feller-buncher, two skidders, two delimiters, two bucksaws, and two loaders were included in the AHA for roundwood; and for chips one skidder, one loader, and one chipper were included. For the Chip treatment the costs of one feller-buncher, one skidder, one loader, and one

Table 4.2: Machine rate assumptions used to calculate hourly costs for each piece of equipment.

Cost factors	Tigercat 822C Feller- Buncher	Tigercat E620C Skidder	Tigercat 625C Skidder	Tigercat 250 Loader	Tigercat 240B Loader	Conehead 580 Chipper	CSI 4400/3000 Delimber/ Buck Saw
Purchase Price ^a	\$400,000	\$225,000	\$285,000	\$185,000	\$160,000	\$239,000	\$105,000
Insurance & Taxes (% of average yearly investment) ^b	3.50%	5%	5%	1.50%	1.50%	5%	2%
Maintenance & Repair (% of Depreciation) ^b	75%	90%	90%	90%	90%	100%	90%
Fuel consumption (liters/hr) ^b	29.9	23.3	27.6	16.8	14.2	53	16.8
Fuel cost (\$/liter)	\$0.63	\$0.63	\$0.63	\$0.63	\$0.63	\$0.63	\$0.63
Utilization rate (%)	60% ^b	60% ^b	60% ^b	60% ^b	65% ^b	50% ^c	35% ^c

^aPurchase prices were estimated through consultation with equipment dealers familiar with this harvesting system.

^bSource: Brinker et al. (2002).

^cEstimated from activity samples taken during the study.

chipper were included in the AHA. The AHA selected a system rate ($t\ smh^{-1}$) for each treatment based on the productivity of the least productive function [41]. For the chipping portion of the Integrated treatment the system rate was constrained by the skidding function; however, the chipper utilized limbs and tops from the roundwood portion of the treatment that did not have to be skidded to the chipper; therefore, the system rate was increased to reflect the production of limbs and tops by the roundwood portion of the operation. This was estimated by multiplying the proportion of each merchantable tree that was left over for chipping by the hourly production

rate of roundwood. We assumed that 75% of the non-merchantable weight of each merchantable tree arrived at the chipper. Transportation costs were assumed to be \$0.075 t⁻¹ km⁻¹ with a minimum haul distance of 64 kilometers for both energy chips and roundwood [42]. All costs and prices are listed in US\$ and all weights are reported based on green weight.

4.3.3 Harvesting System Data Collection and Productivity Estimation

During harvesting, elemental time studies were conducted on the feller-buncher, skidders, loaders, and chipper. Activity or work sampling was conducted at the landing in order to determine utilization for the loaders and chipper [38].

4.3.3.1 Felling

One hundred seventy-five felling cycles were observed in each of the nine experimental units, with the exception of one which had 151 cycles recorded. A felling cycle began when a bunch was released and ended when the next bunch was released. Time per bunch, merchantable and non-merchantable stems per bunch, and delay time were recorded for each felling cycle. Felling productivity in t per productive machine hour (pmh) was calculated using equation 1. Stem weights were estimated from data collected during the preharvest inventory.

Felling Productivity (t / pmh) =

$$\left[\left(\frac{\text{average number of merchantable stems per bunch}}{\text{average time per bunch (hrs) (excluding delays)}} \times \text{t per merchantable stem} \right) + \left(\frac{\text{average number of non-merchantable stems per bunch}}{\text{average time per bunch (hrs) (excluding delays)}} \times \text{t per non-merchantable stem} \right) \right] \quad (1)$$

4.3.3.2 Skidding

A minimum of 25 skidder cycles were recorded in each experimental unit. Time per cycle, merchantable and non-merchantable stems per cycle, skid distance, and delay time were recorded for each skidding cycle. Skidding trees from stump to landing consisted of two steps. The first step involved accumulating stems at the stump and skidding them to an intermediate

collection point or staging area. A cycle for this step began when stems were dropped at the intermediate collection point and ended when the next accumulation was dropped at the intermediate collection point. The second step consisted of accumulating stems from the intermediate collection point and dropping them at the loader. The time and skid distance for the two steps were summed to yield total turn time and skid distance. Skidder productivity was estimated using equation 2 for each skidder in each unit. In treatment B, skidder turns that went to the chipper were separated from those that went to the loader. Weight per stem was estimated using data collected during the preharvest inventory.

Skidding Productivity (t/pmh) =

$$\left[\left(\frac{\text{average number of merchantable stems per turn}}{\text{average turn time (hrs) (excluding delays)}} \times t \text{ per merchantable stem} \right) + \left(\frac{\text{average number of non-merchantable stems per turn}}{\text{average turn time (hrs) (excluding delays)}} \times t \text{ per non-merchantable stem} \right) \right] \quad (2)$$

4.3.3.3 Loading

Both activity sampling and elemental time studies were conducted on the loaders. Activity samples were conducted at forty-five second fixed intervals. Sampling categories included: sorting, delimiting, bucking, loading truck, waiting on truck, waiting on skidder, mechanical delay, non-mechanical delay, and idle. An elemental time study was conducted when trailers were being loaded and included time per load and delay time. Because the loaders loaded the same trailer simultaneously, loading productivity was estimated for the loading function rather than for each machine. Loading productivity ($t \text{ pmh}^{-1}$) was estimated by dividing average truck payload (from scale tickets) by average loading time and multiplying by the utilization percentage determined by activity sampling.

4.3.3.4 Chipping

Both activity sampling and an elemental time study were conducted on the chipper operations. Activity samples were conducted at forty-five second fixed intervals during chipping. Sampling categories included: chipping, feed-wheel jammed, waiting on loader, waiting on chip van, mechanical delay, non-mechanical delay, and idle. The elemental time study determined the amount of time required to load a chip van, excluding delays. The chipping cycle began when chips started flowing from the chipper spout and ended when chips stopped flowing from the spout. Chipping productivity (t pmh^{-1}) was calculated by dividing chip van payload (from scale tickets) by the time required to load a van, excluding delays.

4.3.4 Statistical Analysis

Harvesting productivity and costs in the three treatments were compared using analysis of variance and the Tukey HSD test. Statistical analysis was performed with SAS v9.1 statistical software [43] using the Proc GLM procedure for a randomized complete block design with three blocks and three experimental units per block. All statistical analyses were conducted at an alpha level of 0.10 unless otherwise stated.

4.4 Results and Discussion

4.4.1 Timber Stand Characteristics

Loblolly pine was the dominant overstory species on the study site; however, pine basal area varied from $10.7 \text{ m}^2 \text{ ha}^{-1}$ in Block 2 to $18.0 \text{ m}^2 \text{ ha}^{-1}$ in Block 1 (Table 4.3). Sweetgum (*Liquidambar styraciflua* L.) was the most common understory species and accounted for 14-39% of basal area. Total understory biomass estimates varied from 7 to 24 t ha^{-1} . Cane had a large presence in the understory of Blocks 2 and 3, but was largely absent in Block 1. Merchantable stems varied from 138 to 190 t ha^{-1} .

Table 4.3: Preharvest estimates of stems per hectare, t per hectare, and basal area ($\text{m}^2 \text{ha}^{-1}$), for the three blocks on the study site in Bertie County, NC. Stem weights and basal area do not include stems with dbh <2.5 cm.

Species	Stems ha^{-1} (≥ 10 cm dbh)	Green t ha^{-1} (≥ 10 cm dbh)	Stems ha^{-1} (< 10 cm dbh)	Green t ha^{-1} (< 10 cm dbh)	Basal Area ($\text{m}^2 \text{ha}^{-1}$)
Block 1					
<i>Pinus taeda</i>	344.2	173.2			18.0
<i>Acer rubrum</i>	14.3	1.4	164.7	1.6	0.6
<i>Liquidambar styraciflua</i>	120.2	12.7	1042.9	6.3	3.2
Other	22.4	3.1	823.3	0.4	0.8
Total	501.1	190.4	2030.9	8.3	22.6
Block 2					
<i>Pinus taeda</i>	157.4	104.7			10.7
<i>Acer rubrum</i>	26.8	9.4	70.6	0.2	0.7
<i>Liquidambar styraciflua</i>	177.1	57.2	1976.0	19.5	7.7
<i>Arundinaria gigantea</i>			5222.3		
Other	3.6	2.5	846.8	5.0	0.9
Total	364.9	173.8	2893.4 ^a	24.7	20.0
Block 3					
<i>Pinus taeda</i>	179.6	114.3			11.2
<i>Acer rubrum</i>	33.7	7.4	224.5	0.2	1.2
<i>Liquidambar styraciflua</i>	121.3	16.1	598.8	7.0	3.8
<i>Arundinaria gigantea</i>			63857.0		
Other	2.2	0.4	149.7		
Total	336.8	138.2	973.0 ^a	7.2	16.2

^aExcludes *Arundinaria gigantea*.

4.4.2 Roundwood Harvesting Productivity and Costs

Roundwood harvesting costs were lower for the Conventional treatment than for the Integrated treatment, although this difference was not statistically significant ($P > 0.25$) (Table 4.4). Many of the results presented are not statistically significant; however, these differences are of significant practical importance for harvesting contractors. According to Timber Mart-South (2010), the mean cut-and-load rate for Coastal Plain final harvests in the third quarter of 2010 was $\$10.73 \text{ t}^{-1}$, which means this contractor would earn $\$1.38 \text{ t}^{-1}$ profit when harvesting the Conventional treatment, if he was being paid this rate. In contrast, at this rate the contractor would lose $\$0.25 \text{ t}^{-1}$ when harvesting roundwood in the Integrated treatment.

The harvesting contractor felled and skidded merchantable ($\geq 10 \text{ cm dbh}$) and non-merchantable stems ($< 10 \text{ cm dbh}$) to the landing separately in the Integrated treatment. This decision achieved its objective of keeping loading productivity high, but had the deleterious effect of reducing felling productivity by an entire truckload per productive hour and skidding productivity was reduced by an average of 6 t pmh^{-1} for each skidder and 12 t pmh^{-1} for the skidding function compared to the Conventional treatment (Table 4.5). These decreases in productivity increased harvesting costs by $\$1.63 \text{ t}^{-1}$ (Table 4.4), the difference between profit and loss at current cut-and-load rates.

Table 4.4: System rate (t smh^{-1}) and harvesting costs (US\$ green t^{-1} onboard truck) of roundwood and energy chips with descriptive statistics. The harvesting cost is the cost of production at the system rate.

Treatment	System rate (t smh^{-1})	Cut & Load Cost (US\$ green t^{-1})			
		Mean	Min.	Max.	Std. Error
Conventional	60.6	9.35 ^a	8.91	9.77	0.25
Integrated					
Roundwood	49.3	10.98 ^{ab}	10.17	12.36	0.69
Chips	15.2	19.19 ^b	16.73	23.40	2.11
Chip	21.8	17.93 ^b	14.83	24.11	3.09

a,b Means not connected by the same letter are significantly different ($\alpha = 0.10$).

The average roundwood system rate in the Conventional treatment was 60.6 t smh^{-1} (105 loads week^{-1}) versus 49.3 t smh^{-1} (87 loads week^{-1}) in the Integrated treatment (Table 4.4). The break-even roundwood production level was 48 t smh^{-1} (85 loads week^{-1}) in the Conventional treatment (Figure 4.1) and 52 t smh^{-1} (91 loads week^{-1}) in the Integrated treatment, assuming a cut-and-load rate of $\$10.73 \text{ t}^{-1}$. Unfortunately, the Integrated treatment does not reach its break-even production level before reaching its system rate. In order for the Integrated treatment to reach its break-even production level, feller-buncher utilization must reach 98%. The increased cost of roundwood in the Integrated system was only approximately $\$0.50 \text{ t}^{-1}$ at the same production level (Figure 4.1); however, low felling and skidding productivity in the Integrated treatment reduced the system rate by 18.6% compared to the Conventional treatment, which increased onboard truck costs at the system rate by $\$1.63 \text{ t}^{-1}$ in the Integrated treatment. This

study suggests that chipping non-merchantable stems can reduce hourly roundwood production, which agrees with previous research [e.g. 27].

Table 4.5: Harvest function costs (US\$ green t⁻¹) and productivity (green t pmh⁻¹ machine⁻¹) with descriptive statistics. Function costs are for each function producing at its intrinsic production level, unconstrained by a system rate.

Function	Treatment	# Machines	Function Cost (US\$ green t ⁻¹)	Productivity (green t pmh ⁻¹ machine ⁻¹)			
				Mean	Min.	Max.	Std. Error
Felling							
	Conventional	1	1.82 ^{aA}	77.21 ^a	76.01	78.52	0.73
	Integrated	1	2.59 ^{aA}	54.90 ^a	46.37	59.68	4.28
	Chip	1	3.48 ^{aA}	51.12 ^a	23.87	78.27	15.70
Skidding							
	Conventional	2	3.02 ^{aA}	38.02 ^a	33.77	45.68	3.84
	Integrated Roundwood	2	3.55 ^{aA}	31.87 ^a	30.40	33.86	1.03
	Integrated Chips	1	12.07 ^{bB}	9.08 ^b	7.94	11.16	1.04
	Chip	1	4.18 ^{aB}	28.53 ^a	16.99	40.43	6.77
Loading							
	Conventional	2	2.99 ^{aA}	42.31 ^a	36.36	53.73	5.71
	Integrated	2	2.64 ^{aA}	46.62 ^a	43.97	51.02	2.21
Chipping							
	Integrated Chips	1	11.53 ^{aA}	18.33 ^a	14.28	21.34	2.10
	Chip	1	6.49 ^{aB}	31.87 ^b	29.86	35.88	2.01

a,b Means not connected by the same letter are significantly different ($\alpha = 0.10$).

The harvesting contractor in this study was able to keep weekly roundwood production above the system rate in the Integrated treatment by increasing the hours worked by the feller-buncher and skidders. Felling in this operation was not dependent on the other functions, and

therefore it was advantageous to have the feller-buncher work on weekends and/or after hours in order to remain ahead of the rest of the crew. Similarly, one or both of the skidders often worked after hours and/or on weekends to skid stems from areas farthest from the landing to staging areas closer to the landing, which reduced the average skid distance and increased skidding productivity while loading and chipping were conducted.

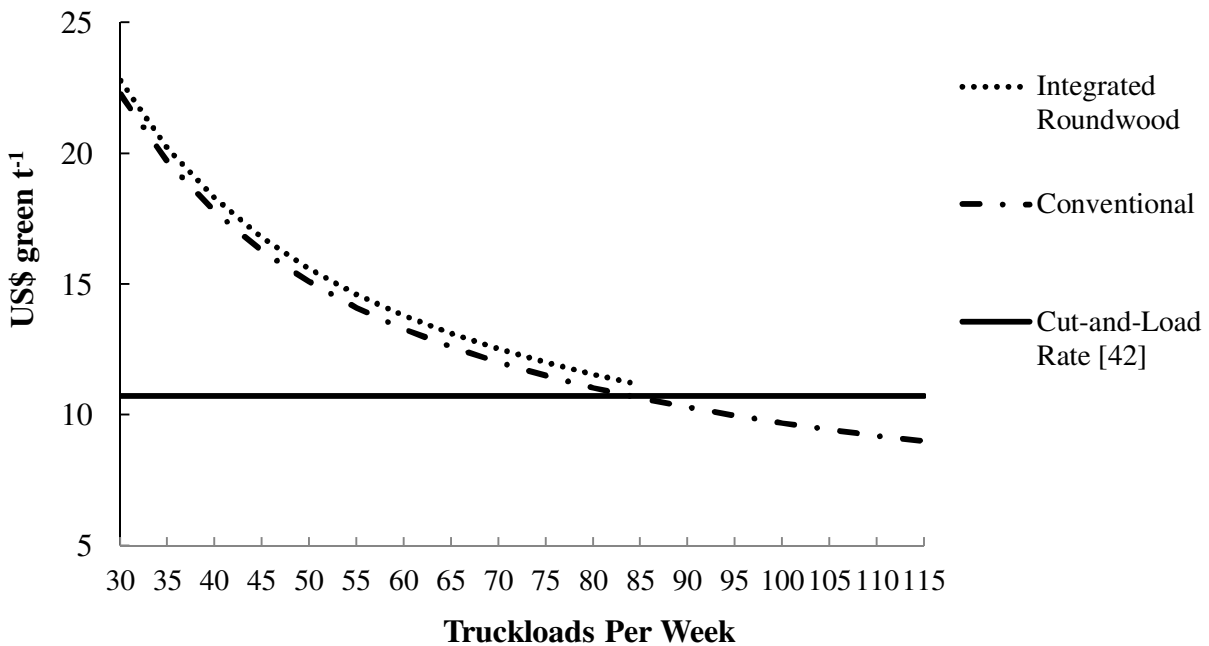


Figure 4.1: Roundwood production cost (onboard truck) as a function of weekly production for the Integrated and Conventional treatments. For this analysis, the average productivity of each function from the three replications was used to determine system costs. The lines on the graph stop when the treatment reaches its system rate. Payload is assumed to be 22.7 t.

4.4.3 Energy Chip Harvesting Productivity and Costs

The mean delivered price of whole tree “dirty” chips in the third quarter of 2010 was \$18.30 t⁻¹ for pine, \$17.86 t⁻¹ for hardwood, and \$18.30 t⁻¹ for hogged fuel (wood that has been

ground in a machine to prepare it for burning; hogs are typically larger and produce more uniform chips than in-woods chippers) [42]. These prices were lower than in previous quarters, possibly because a relatively dry summer allowed chip production to remain high in most areas. Consequently, the estimated cut-and-haul costs for both treatments were well in excess of the market price. The average delivered cost for chips was $\$24.48 \text{ t}^{-1}$ in the Integrated treatment and $\$23.22 \text{ t}^{-1}$ in the Chip treatment, which means the contractor would lose $\$6.18 \text{ t}^{-1}$ or $\$4.92 \text{ t}^{-1}$, depending on the harvest prescription if he were paid $\$18.30 \text{ t}^{-1}$ for whole tree “dirty” chips.

In order for landowners and harvesting contractors to chip merchantable stems for energy use, their profit from fuel chips must equal or exceed the profit received from harvesting roundwood pulpwood. In this operation, the opportunity cost of chipping pulpwood-sized material was approximately $\$20 \text{ t}^{-1}$ when one considers the additional cost of harvesting energy chips and the premium paid for roundwood pulpwood compared to energy chips. During the third quarter of 2010, the delivered price of roundwood pine pulpwood was slightly less than $\$30 \text{ t}^{-1}$ [42]. At this price for roundwood pulpwood, the delivered price of energy chips must be in excess of $\$38.50 \text{ t}^{-1}$ in order for landowners and harvesting contractors to be indifferent between delivering pulpwood-sized material as roundwood pulpwood and energy chips (Figure 4.2). If roundwood pulpwood prices fell to $\$25 \text{ t}^{-1}$ delivered, landowners and loggers would be indifferent between delivering the two products if chip prices were over $\$33.50 \text{ t}^{-1}$. However, at this price the energy cost of the wood would not be competitive with traditional energy sources. At recent prices for coal [44], in order for wood to be competitive with coal on an energy basis in the South Atlantic region (DE, DC, FL, GA, MD, NC, SC, VA, WV) the delivered price of wood should not exceed $\$20 \text{ t}^{-1}$ [45]. Of course, coal is most often delivered by rail, whereas wood is

typically delivered by truck. If an energy facility did not have rail access, then the energy cost of coal would be higher and the energy price of wood could be more competitive.

Onboard truck chip costs were reduced in the Chip treatment compared to the Integrated treatment, but were still $\$8.58 \text{ t}^{-1}$ higher than the cost of roundwood in the Conventional treatment (Table 4.4). Chip costs in the Chip treatment could have been reduced from $\$17.93 \text{ t}^{-1}$ to nearly $\$15 \text{ t}^{-1}$ (onboard truck) if skidding productivity had averaged 35 t pmh^{-1} as it did for each skidder in the Conventional treatment. Chipper productivity was 74% higher in the Chip treatment compared to the Integrated treatment (Table 4.5). Chipper productivity was reduced in the Integrated treatment because non-merchantable stems did not feed into the chipper as well as larger stems. In addition, the feller-buncher often worked several days ahead of the rest of the crew, which allowed the non-merchantable stems time to dry out prior to chipping and reduced their weight. In order for chipping to be profitable, skidding and chipping productivity must be increased substantially from study observations.

Because merchantable and non-merchantable stems were skidded to the landing separately in the Integrated treatment, skidder productivity fell below 10 t pmh^{-1} when delivering wood to the chipper (Table 4.5), which resulted in chip costs of nearly $\$20 \text{ t}^{-1}$ (onboard truck) (Table 4.4). As a result, chip costs for the Integrated treatment were much higher than those reported in past studies of tree-length systems [26,27,46], but were lower than those reported in a cut-to-length thinning/fuel reduction treatment [47]. This study suggests that when harvesting energywood, merchantable and non-merchantable stems should be felled and skidded simultaneously in order to keep felling and skidding productivity at acceptable levels.

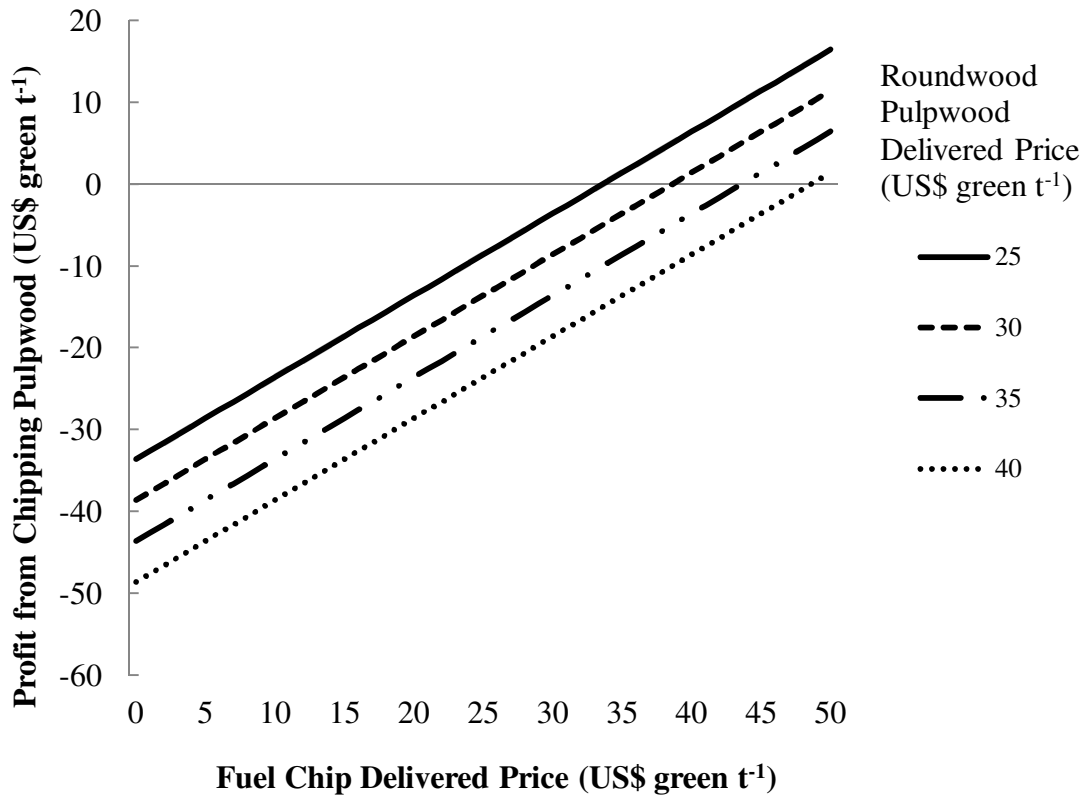


Figure 4.2: Profit from chipping roundwood pulpwood for a range of energy chip and roundwood pulpwood delivered prices. Profit from chipping pulpwood is calculated as follows:
 Profit from chipping pulpwood = (delivered price of energy chips – cut and haul cost of energy chips) – (delivered price of roundwood pulpwood – cut and haul cost of roundwood pulpwood).

The logger fed the chipper in the Integrated treatment with a loader devoted specifically to that function, rather than feeding the chipper with one of the loaders processing and loading roundwood. This loader represented an additional cost that was applied solely to the cost of producing energy chips. Lower capacity loggers may be able to reduce chip costs by feeding the chipper with a loader that also processes roundwood. Using a roundwood loader to feed the chipper presents challenges for high production loggers because so much of the loader's time is spent loading roundwood that it may be difficult to devote sufficient time to feeding the chipper.

In this case, it would be necessary to cold-load chip vans or chip outside of normal working hours so that roundwood loading would not be interrupted.

In addition to low skidder and chipper productivity in the Integrated and Chip treatments, equipment costs were higher than in past studies. The combined initial purchase prices for one feller-buncher, skidder, loader, and chipper in this study was nearly \$500,000 higher than the purchase prices assumed by Baker et al. [27] (Table 4.2). Specifically, the feller-buncher in this study cost \$200,000 more than the one employed by Baker et al. [27] and one of the skidders cost \$65,000 more and the other cost \$120,000 more than in the aforementioned study. On the other hand, this study did not employ a \$360,000 processor as did the study by Baker et al. [27]. In addition, the fuel consumption assumed in this study was considerably higher than the fuel consumption assumed by Baker et al. [27]. The logger in this study was equipped for high production and wet-site harvesting, and therefore owned equipment that cost more and used more fuel than many loggers. This study demonstrates that loggers such as this one are less capable of cost effectively harvesting and transporting wood for energy from pine plantations than loggers with lower capitalization and more fuel efficient equipment. This research suggests that wet-site loggers may not be able to profit from energywood harvesting until the wood-energy market expands and prices for energywood rise considerably. Additional research is needed to assess the harvesting costs associated with harvesting energywood from hardwood stands. Of particular interest to wet-site loggers such as the one employed in this study is the cost of harvesting energywood from bottomland sites.

4.4.4. Biomass Utilization

The Chip Treatment resulted in the greatest harvest volume per ha and the lowest residual biomass per ha of the three treatments (Figure 4.3). The Conventional treatment produced more

roundwood per ha than the Integrated treatment; however, this was largely due to low per ha roundwood availability in the Integrated harvest unit in Block 2. In Block 3, the Integrated treatment actually produced more t ha^{-1} of roundwood than the Conventional treatment.

The residual biomass shown in Figure 4.3 includes both standing and down wood within the harvest units, but does not include limbs and tops that were brought to the landing. In the Integrated and Chip treatments a majority of this material was chipped; however, in the Conventional treatment this material was piled around the landing and used as a mat for the skidders in order to minimize soil disturbance. Therefore, the residual biomass following the Conventional treatment is slightly greater than displayed in Figure 4.3. During wet-weather this material may have greater value serving as a slash mat for skidders than for energy chips and therefore may not be available to produce chips. The area around the deck receives heavy skidder traffic and without these slash mats rutting may occur during wet-weather harvesting [48].

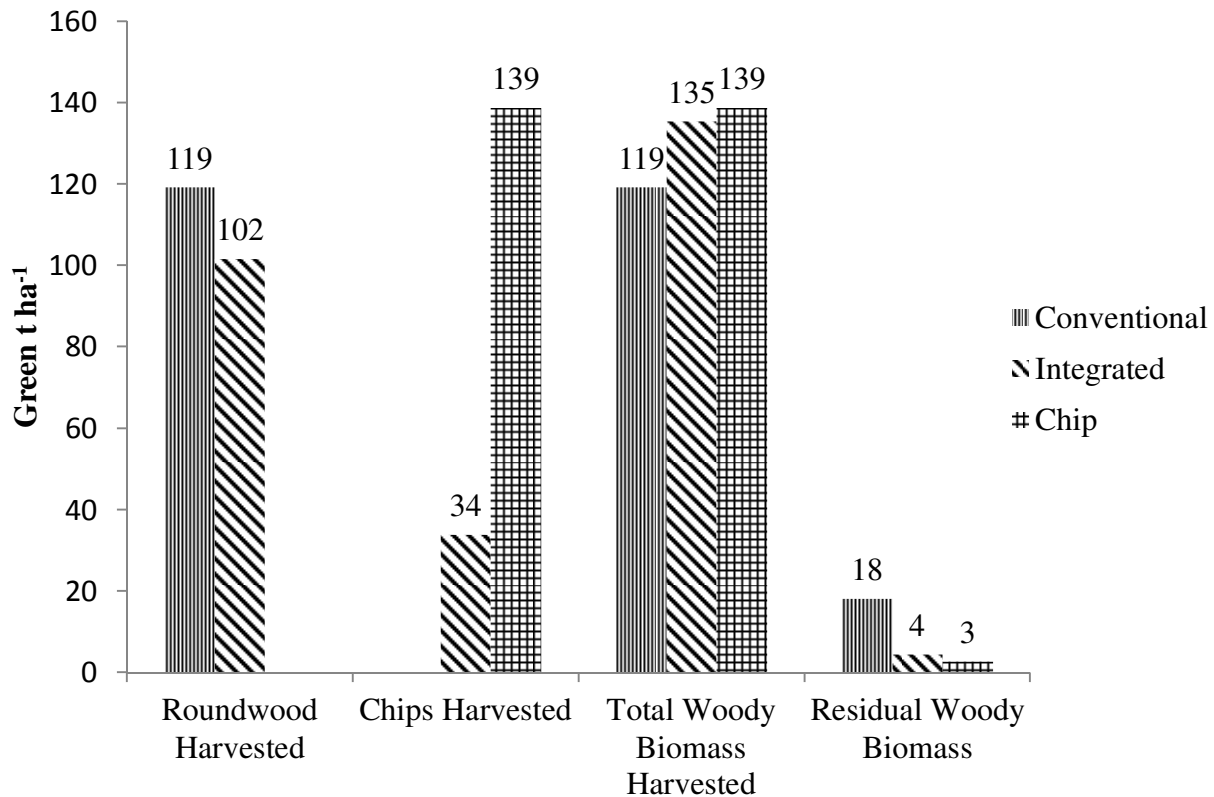


Figure 4.3: Green t per hectare of roundwood and chips harvested, total woody biomass harvested, and residual woody biomass following three harvest prescriptions. Residual woody biomass includes both standing and down woody biomass excluding residuals that were piled at the landing because this material was used as a mat for skidders and could not be measured accurately.

4.5 Summary and Conclusions

The Conventional and Integrated treatments of this study document how harvesting energywood can change the dynamics of each function of the harvesting system. Harvesting energywood reduced the productivity of the felling and skidding functions, thereby reducing hourly system productivity and increasing system costs (Table 4.4, Table 4.5). Felling and

skidding roundwood and energywood simultaneously and separating the energywood at the landing may increase system productivity and reduce costs; however, this would certainly reduce roundwood loading productivity and loggers may be hesitant to risk a production bottleneck at the landing.

Using the harvesting system employed in this study, energy chips can be produced from pulpwood-sized material and non-commercial stems at a lesser cost than relying solely on harvesting residues and non-merchantable stems (Table 4.4). However, with the price of energy chips 40% lower than the delivered price of roundwood pulpwood [42], it is not currently economical for loggers and landowners to chip whole trees that could be sold as roundwood pulpwood. Furthermore, with the harvesting equipment utilized in this study, the cost of producing energy chips using pulpwood and small-diameter material was approximately 75% higher than producing roundwood in the Conventional treatment. In order for loggers and landowners to be indifferent between harvesting energy chips and pulpwood, the price of energy chips would need to be twice its current level. If less expensive and more fuel efficient equipment were employed, the cost of the Chip treatment could probably be reduced significantly, making the difference in harvesting costs between roundwood and chips much less. Biomass utilization was similar between the Integrated and Chip treatments; and both had higher biomass utilization than the Conventional treatment (Figure 4.3). The Integrated treatment did not significantly reduce the amount of roundwood produced per ha compared to the Conventional treatment.

This study indicates that loggers capable of harvesting wet-sites, such as the one studied here, are unlikely to harvest energywood at a competitive cost with loggers with lower capitalization and more fuel efficient equipment. The loggers observed by Westbrook et al. [26]

and Baker et al. [27] had significantly lower capitalization, more fuel efficient equipment, and were therefore able to produce energywood at a much lower cost than the logger in this study. Unless wet-site loggers can utilize sufficient volumes of currently non-merchantable material that is brought to the landing during normal operations, they may not be able to profit from harvesting energywood. Wet-site loggers should minimize their handling of small-diameter material until energywood prices appreciate considerably.

Finally, based on the findings of this study and previous research, the following recommendations can be made to harvesting contractors regarding the production of energywood:

- Until energywood prices appreciate considerably, roundwood production should not be sacrificed for the purpose of increasing energywood production,
- Producing energy chips in an integrated treatment has the potential to reduce hourly roundwood production, although this will depend on the logger and site conditions,
- Roundwood can be produced at a lower cost than energy chips,
- Loggers with low capitalization and fuel efficient equipment will have an advantage in producing energywood at low cost over wet-site loggers with less efficient equipment,
- Harvesting energywood can improve biomass utilization, reduce slash remaining on-site after harvest, and potentially reduce site preparation costs [26].

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5.0 CONCLUSION

The purpose of this study was to investigate the expected impact of a vibrant wood-energy market on the southern wood supply chain, which consists of landowners, harvesting contractors, and the forest products industry (Sun and Zhang, 2006). This study is unique in that it examined the expected impact of an expanded wood-energy market from the perspective of each member of the southern wood supply chain. Results relating to landowner expectations can be used by extension personnel to guide outreach programs to landowners regarding wood-based energy. Insight from forest products industry mills regarding competition between industries should be taken into account when developing incentive programs for wood-based energy. Information relating to energywood harvesting costs should be taken into account when projecting wood procurement costs for wood-energy facilities. This information is also useful for harvesting contractors in deciding whether or not to purchase equipment for harvesting woody biomass for energy. This chapter will synthesize the results of this study and will draw conclusions about the expected impact of a vibrant wood-energy market on each member of the southern wood supply chain.

5.1 Landowners

Private landowners own nearly 90% of forestland in the U.S. South (Butler, 2008), and therefore will play a major role in the success or failure of wood-energy ventures in the South. It is difficult to envision a downside for private landowners if a vibrant wood-energy market emerges. The only potentially negative impact on landowners would occur if a subsidized wood-energy market displaced existing forest products industry mills, only to have their subsidies eliminated. However, this is unlikely at the present time given the limited scope of the wood-energy market. At present, there are insufficient markets for timber, especially small-diameter

material, in many areas of the South. This suggests that an expanded wood-energy market will benefit landowners.

Nearly three quarters of responding consulting foresters in chapter 2 suggested that timber markets were inadequate. Likewise, more than 90% of these respondents suggested that mill shutdowns and reductions have reduced the profitability of their timber sales. This strongly suggests that there is timber available to support a vibrant wood-energy market. Furthermore, ninety percent of private and public landowners in chapter 3 suggested that they are willing to sell timber to a wood-energy facility, which suggests that landowners plan to take advantage of an expanded wood-energy market if given the opportunity. These results agree with other recent surveys of forest landowners in the U.S. South that suggested a majority of landowners are willing to sell wood for energy use (Joshi and Mehmood, 2011; Paula et al., 2011).

Private forestland in the southern United States can be converted to other uses such as agriculture or development if returns from forestry are less than returns from other uses. Many ha of forestland in the South have been converted from one use to another over the past two centuries. When Europeans settled the continent they converted millions of hectares from forests to agriculture. During the 20th century, many marginal agricultural fields were converted back to forestland, many as pine plantations. A vibrant wood-energy market may provide landowners with additional revenues, and may make them less likely to convert their forest to another use. Two-thirds of respondents in chapter 3 suggested that a vibrant wood-energy market would make them less likely to convert their forest to another use. Furthermore, more than 80% of consulting foresters in chapter 2 suggested that a vibrant wood-energy market would improve the profitability of their clients' forestland investments. Past research indicates that bioenergy opportunities could increase land values by \$70-\$92 ha⁻¹ (Nesbit et al. 2011).

An issue of paramount importance for landowners is the price they will be paid for energywood. At this time landowners often receive \$1-3 t⁻¹ or less for energywood, which is less than half of what they receive for pulpwood (Timber Mart-South 2010). However, when site preparation savings are taken into account, the value of energywood can approach the market price of pulpwood (Conrad and Bolding, 2010). Additionally, an expansion of the wood-energy market is likely to raise energywood prices, which would obviously benefit landowners.

5.2 Forest Products Industry

The traditional forest products industry has the most to lose from a vibrant wood-energy market. If wood-energy facilities compete for wood with forest industry mills, then the price of wood is likely to increase, which could put domestic mills at a competitive disadvantage with foreign mills. If public demand for wood-energy creates demand and drives up the price of wood, then the forest products industry would have no justifiable complaint because the wood-energy facilities are supplying a more valuable product to the market place. However, wood-energy ventures are often subsidized or mandated by government policies such as the Biomass Crop Assistance Program (BCAP), renewable portfolio standards, renewable fuels mandates, and in Europe, the Kyoto Protocol. BCAP, in particular, has already caused raw material costs to rise for certain segments of the forest products industry (Eilperin, 2010). These mandates and subsidies suggest that wood-energy ventures may not be able to succeed on their own at the present time, and these subsidies enable the transfer of wood from a higher to a lower value use.

To date, there has been only localized competition between the forest products and wood-energy industries because most areas in the South do not have vibrant wood-energy markets. However, ninety-five percent of fibermills (pulp/paper and composite mills) and 77% of

sawmills in chapter 3 suggested that wood-energy facilities will compete for wood with forest industry mills. Similarly, two-thirds of responding consulting foresters in chapter 2 expected competition between mills and energy facilities. More than 70% of all respondents in chapter 3 expected stumpage prices to increase if inter-industry competition occurs.

Fibermills were the least supportive of government policies promoting wood-based energy of any of the groups surveyed in this study. More than 90% of responding fibermills expected tax breaks and subsidies for wood-energy companies to make forest industry mills less competitive in purchasing wood. However, to this point the forest products industry has been one of the biggest beneficiaries of wood-energy and wood-energy subsidies. The forest products industry owns a majority of the cogeneration facilities in this country (Bain and Overend, 2002). In addition, the pulp and paper industry received approximately \$6 billion from the federal government for mixing diesel fuel with black liquor in their boilers (AccuVal Associates, 2010). These subsidies literally made the difference between profit and loss for International Paper in 2009.

If respondents in chapters 2 and 3 are correct and competition does occur and stumpage prices rise, then the forest products industry is clearly the loser, that is, unless the forest products industry is able to produce and sell energy from wood. The forest products industry has the infrastructure in place to supply energy from wood, and the pulp and paper industry has been producing energy from wood in their mills for over two decades. Past research suggests that the forest products industry should begin producing and selling a wider array of forest products including: cellulosic ethanol, electricity, chemicals, as well as traditional products such as pulp and paper and lumber (Frederick et al., 2008; Winandy et al., 2008).

If the wood-energy market does expand in a meaningful way, then the traditional forest products industry will have to make adjustments. The recent divestment of timberland by most forest products companies may have reduced their leverage, especially in the absence of long-term wood supply agreements. More than three-quarters of the wood procured by energy facilities consists of whole tree chips and mill residuals. In contrast, nearly 80% of the wood purchased by fibermills is in roundwood or clean chip form. If the wood-energy market expands, then timber that was previously delivered as roundwood or clean chips to a pulpmill could be delivered to an energy facility.

When asked about procurement practices, the only strategy that a majority of both fibermills and wood-energy facilities suggested would increase was the use of long term wood supply agreements. Energy companies are accustomed to multi-decade contracts, and so this is not a change in practice for them. Fibermills, on the other hand, typically buy wood on the open market, and therefore long term wood supply agreements, when not connected with timberland divestment, are a new practice.

Another procurement practice endorsed by fibermills is increasing inventory in the wood yard. Wood-fired power plants' demand for wood often varies seasonally, and therefore fibermills may be able to reduce procurement costs by stocking extra wood in their yard before peak demand from energy facilities causes prices to increase. The downside of this approach is that wood quality tends to deteriorate when it is allowed to remain in the wood yard for extended periods.

5.3 Foresters

This study did not investigate the impact of a vibrant wood-energy market on foresters, specifically; however, foresters typically work for one of the groups investigated in the study and therefore will be affected by a vibrant wood-energy market. Consulting foresters typically work for landowners, and therefore there is little downside for this constituency. The same holds true for foresters employed by timberland investment management organizations (TIMOs) and real estate investment trusts (REITs). Most responding consulting foresters in chapter 2 suggested that a vibrant wood-energy market would improve the value of their clients' investments, which suggests that the wood-energy market would also benefit these foresters.

More than 90% of responding consulting foresters reported a decline in the number of forest industry mills in their area, and nearly three-quarters of respondents reported inadequate timber markets in their area. An expanded wood-energy market would provide an additional buyer of timber, which could only benefit consulting foresters as well as foresters working for TIMOs and REITs. The wood-energy market could also provide a market for currently non-merchantable timber, which could make pre-commercial thinnings and fuel reduction treatments profitable, or at least less expensive. To date, landowners and their foresters have received very little compensation from harvesting wood for energy. Only 12% of private landowners and consulting foresters reported having sold timber to an energy facility. Furthermore, more than half of wood-energy facilities in chapter 3 reported that less than 5% of the price they pay for wood goes to landowners and nearly 90% reported that less than 15% of the price paid for wood goes to the landowner. This means that most landowners receive less than \$3 t⁻¹ for energywood. Therefore, foresters that are paid a commission of 10% or less receive under \$0.30 t⁻¹ for

energywood at current prices (Timber Mart-South 2010). This would obviously change if wood-energy markets expanded and prices increased.

Consulting foresters in this study suggested that the average harvest tract size has been declining over the past decade and this trend is expected to continue over the next decade. Additionally, the vast majority of responding consulting foresters in this study reported conversion of forestland to development. If the forest products industry continues to decline, and the price of timber is reduced, then the value of holding forestland will decline and there will be increased pressure on landowners to convert their forestland to other uses. A vibrant wood-energy market may keep timber prices at acceptable levels and thereby encourage forest landowners to keep their land forested, which would obviously benefit most foresters.

For many years the forest products industry has been a primary employer of foresters. As stated previously, the forest products industry has the greatest potential downside in the event of an expanded wood-energy market. Therefore, foresters employed by the forest products industry have the greatest potential downside of any group of foresters. On the other hand, competition from energy facilities will put pressure on forest industry mills wood procurement operations, and may increase opportunities for procurement foresters.

Many mills procure wood through the use of wood dealers who employ foresters to purchase timber from landowners and then market it to mills. A majority of wood-energy facilities in chapter 3 suggested that wood-energy facilities should increase their wood purchases from dealers. Therefore, opportunities for foresters to work for wood dealers could increase as timber markets become more complex and there are a larger number of facilities for dealers to market timber.

If wood-energy markets expand, then some forestry jobs will be created at wood-energy facilities. For example, wood pellet manufacturer Green Circle Bio Energy Inc. employs a former forest industry forester to manage their wood procurement (Green Circle Bio Energy, Inc., 2011). Similarly, Fram Renewable Fuels, LLC, another wood pellet manufacturer, employs a former Rayonier and International Paper forester to manage its wood procurement (Fram Renewable Fuels, LLC, 2011). Wood-fired power plants generally have similar positions as well. As additional wood-energy facilities are brought to production, new positions are likely to be created for foresters.

5.4 Harvesting Contractors

A primary concern for harvesting contractors with an expanded wood-energy market is their ability to economically harvest and transport energywood. Previous research indicated that energy chips could be produced for between \$8 and \$14 green t⁻¹ onboard truck (Westbrook et al., 2007; Baker et al., 2010). Chapter 4 sought to expand upon this research by investigating the productivity and cost of fuel chip production by loggers with larger capital investments than those in previous studies. This study also sought to compare the productivity and cost of chipping both merchantable and non-merchantable stems together to the productivity and cost of an integrated roundwood and fuel chip system.

Chipping roundwood and energywood together cost in excess of \$7 t⁻¹ more than roundwood (onboard truck) in a traditional system. In addition, the cost of chips in the Integrated treatment was nearly \$10 t⁻¹ more than roundwood harvested using a traditional system. The Integrated treatment raised the cost of roundwood by reducing the system rate by approximately 11 t per scheduled machine hour. The cost of producing energywood (onboard truck) in the Chip

treatment was more than \$3 t⁻¹ higher than the highest cost treatment found in the study conducted by Baker et al. (2010). Similarly, the cost of producing energywood in the Integrated treatment was nearly \$5 t⁻¹ higher than the highest cost treatment observed by Baker et al. (2010).

The only treatment in this study that produced a profit at current cut-and-load rates was the Conventional treatment. This indicates that higher prices for energywood are necessary before loggers such as the one observed in this study produce energywood as chips. Loggers with smaller capital investments and more fuel efficient equipment should be able to reduce energywood harvesting costs to the levels observed by Baker et al. (2010). However, until energywood prices increase substantially, loggers should not sacrifice roundwood production in order to increase fuel chip production.

Chapter 4 demonstrates that large scale, wet-weather capable loggers should be the last loggers to attempt fuel chip harvesting, unless they are able to utilize material that is brought to the landing during normal operations in sufficient volumes to be profitable. Large machines with dual tires and high payload capabilities are severely underutilized harvesting small-diameter material, and this results in high per-tonne costs. Smaller machines would have lower fixed costs, use less fuel, and utilize a greater percentage of their payload capacity.

Another important observation from chapter 4 is the importance of selecting a proper system for delivering energywood from the stump to the landing. This study demonstrated two methods of delivering energywood to the landing. The first method was for the feller-buncher to separate energywood and roundwood at the stump and skid the materials separately to the landing. The second method was for the feller-buncher to fell merchantable and non-

merchantable stems together, with the two materials skidded to the landing simultaneously. Separating energywood at the stump resulted in stump-to-deck costs that were \$2.62 t⁻¹ higher than separating energywood at the landing (Conrad and Bolding, 2011). These findings suggest that energywood and roundwood should be felled and skidded simultaneously and separated at the landing.

An expanded wood-energy market should benefit harvesting contractors overall. Unless the wood-energy market displaces the traditional forest products industry, loggers will have the option to continue harvesting and delivering roundwood to mills as at present. On the other hand, loggers with the right equipment mix may be able to improve profitability by delivering wood for energy. Loggers that utilize energywood may be more competitive in procuring timber because greater utilization will be appealing to landowners who value potential site preparation savings. At the very least, an expanded wood-energy market would serve as a hedge against a decline in the forest products industry.

5.5 Summary

In conclusion, this study suggests that the wood-energy market is expected to have a significant impact on the southern wood supply chain. The magnitude of this impact will depend on the scale of the wood-energy market, the spatial distribution of wood-energy facilities in relation to forest industry mills, and the design and extent of government programs promoting wood-based energy. As stated previously, the forest products industry has the largest potential downside if a vibrant wood-energy market emerges. However, if the forest products industry is negatively impacted, there may be negative implications for other wood supply chain members as well.

The preferred outcome for most southern wood supply chain constituents is that wood-energy facilities fulfill a niche role in the southern wood supply chain, and not directly compete with the existing forest products industry. Under this scenario, the wood-energy market would utilize process residuals, logging slash, non-commercial stems, and surplus pulpwood. In this case the wood-energy market would supplement, rather than compete with, the traditional forest products industry. It has been suggested that through improving forest practices and utilizing more forest residues the U.S. could generate 10% of its energy from wood (Zerbe, 2006). Of course, wood is not the only potential source of renewable energy; therefore, if America gets 10% of its energy from wood, and other renewable sources are utilized as well, then fossil fuel usage could be reduced significantly, without negatively impacting the forest products industry.

The effects of a vibrant wood-energy market are yet to be realized, and may never be. The cost of producing energy from wood is still substantially higher than energy from fossil fuels in most applications, making the adoption of wood-energy less likely in the absence of significant government incentives and mandates. A weak U.S economy from 2008-2011 coupled with state and federal budget deficits may have reduced the likelihood of significant additional public sector investments in wood-energy. Furthermore, the failure of recent climate change legislation has reduced the likelihood that emissions from fossil energy will be taxed, which would have made wood-energy less expensive comparatively.

The southern wood supply chain faces a number of challenges today in addition to the uncertainty regarding wood-based energy. These challenges are outlined in chapter 2 and include but are not limited to: increasing urbanization, decreasing harvest tract size, changes in forest management associated with new forest ownership, and uncertainty surrounding the future of the logging industry.

Future research is needed in each of these areas so that foresters can better meet the needs of their clients in a changing marketplace. Additional research is also needed to reduce the cost of producing energy from wood in conversion facilities. Additional forest operations research is needed to investigate the productivity and costs of harvesting energywood using multiple equipment configurations operating under diverse stand conditions. Continued research is needed in the areas of silviculture and genetics to ensure a sufficient supply of timber for both the forest products and wood-energy industries.

Regardless of the challenges faced, it is a fascinating time to be a part of the southern wood supply chain. The challenges and opportunities presented over the next decade will provide opportunities for foresters to once again be stewards of southern forestland and help to meet the needs of society.

5.6 References

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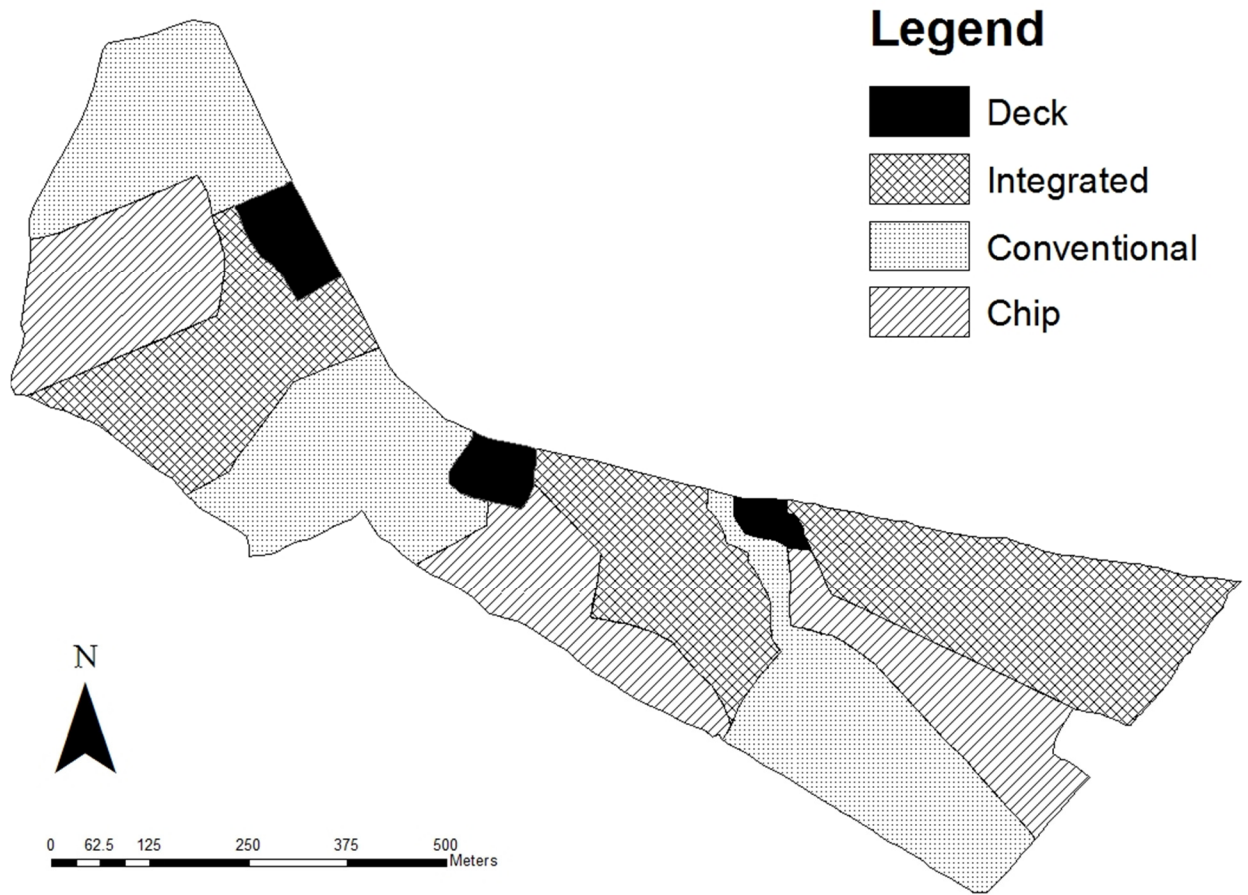
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APPENDIX



Appendix A: Map of the study area in chapter 4, located in Bertie County, NC, showing the three blocks and three harvest treatments within each block.