THE USE OF MECHANICAL THINNING TREATMENTS IN MANAGEMENT OF SMALL STANDS AT THE WILDLAND URBAN INTERFACE

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THE USE OF MECHANICAL THINNING TREATMENTS IN MANAGEMENT OF SMALL STANDS AT THE WILDLAND URBAN INTERFACE

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THESIS ABSTRACT

THE USE OF MECHANICAL THINNING TREATMENTS IN MANAGEMENT OF SMALL STANDS AT THE WILDLAND URBAN INTERFACE

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This study analyzed the productivity and costs of mechanical thinning at the Wildland Urban Interface (WUI). It compared conventional commercial first thinning practices in even-aged loblolly pine plantations in the Southeast US to alternative mechanical thinning treatments with more intense removals intended to promote transition to uneven-aged stand management. Production data of harvesting operations were collected at six harvesting sites in Alabama, Georgia, and Mississippi, USA. The harvesting system of all sites employed 1 feller-buncher, 1 wheeled skidder and 1 knuckleboom loader, and 3 or 4 crew members. Elemental time study information was collected on the skidder and on the feller-buncher using a portable video camera system, and work sampling technique was applied to the loader.

Regression of the time study data indicated no treatment difference for skidder and feller-buncher cycle time. Skid distance and bunch size variables most significantly affected skidder cycle time. Increases in these variables increased skidder cycle time. For the feller-buncher, the number of trees per accumulation and thinning method significantly affected cycle time. Selection within leave rows and larger accumulations resulted in longer cycles. Loader utilization was affected by treatment and was higher for the heavy removal.

Costs analysis was completed for three potential thinning treatments, conventional, heavy, and patch treatments. Harvest costs were compared for three of the six study sites and for three stand sizes (4, 8, and 12ha). Increased stand size reduced costs by lowering fixed costs per unit of move in and set up activities. Treatment differences were greatest for the 4ha stand, where the greatest gain in residual value was observed. Site differences influenced harvesting residual values through wood product value (proportion of pulpwood and chip and saw) and total volume harvested.

The results of this study indicated a potential benefit for landowners from the alternative mechanical treatments. The greater volume removed by the alternative treatments resulted in significant gains in residual values. Increased residual values make small tracts more marketable for landowners and more attractive to buyers and loggers.

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I. INTRODUCTION

Urbanization converts rural lands to urban uses, expanding the interface between human population and rural land. The interface is known as the Wildland Urban Interface (WUI). Definitions found in the literature refer to WUI as an area located somewhere between the urban and the wildland (natural) environment. According to Nowicki (2001), the term WUI was first used in 1974 by a physicist named C.P. Buttler. Nowicki (2001) defined WUI as “the areas where forests meet urban development, particularly houses. It is that area where human improvements (i.e. ranches and farms) come in contact with the wildlands”. It is estimated that over 1.2 million hectares of urban development are added annually in the US (U.S. Department of Commerce, Bureau of the Census 2000). The conversion of rural lands to urban uses changes the way that the forests are valued and managed (Cordell and Macie 2002), and alternatives are being sought to adapt management techniques to the economic, social, and silvicultural issues associated with WUI. The purposes of this discussion are to outline the effects of the expansion of WUI in the Southeast US, the problems associated with its management, and the challenges faced by forest managers at the WUI. Potential mechanical treatments for WUI management will be developed to address those concerns. I will emphasize management challenges in terms of social, silvicultural, and economic concerns.

Problems Associated with the WUI Expansion

The expansion of residential and urban areas may result in significant changes on the wildland environment. Urban residents moving to a wildland interface frequently are unfamiliar with forest management and are often intolerant of certain harvesting practices and aesthetic changes in the forest (Kundell et al. 2002). In many places the current land use policies encourage or allow private landowners to make decisions that are in their own best interest without regard for benefits to the community (Kundell et al. 2002).

One direct effect of urbanization on forest ecosystems is the fragmentation of the forest cover. Indirectly, the process of urbanization affects the forest ecosystems by modifying hydrologic patterns, altering nutrient cycling, fragmenting wildlife habitats, changing atmospheric conditions, and introducing non-native species (Zipperer 2002). As a long-term consequence of the process of urbanization, the original composition, structure, and function of wildland interfaces will change. The “new” forests will be composed of species adapted to the stress caused by urbanization. Changes in species composition create new challenges for wildland managers (Duryea and Hermansen 2002), and can directly affect the forest health and increase fire hazards at the interface. It is believed that even if the urbanization process stops, forests would still be indirectly affected by stresses caused by urban uses such as air pollution and introduction of non-native species (Zipperer 2002).

Forest Health at the WUI

Generally a forest is considered healthy if it has balance among growth, mortality, and regeneration, and if it has the ability to resist and recover from impacts of various stressors. Major stressors of forest health are associated with the expansion of the WUI, including changes in flora plant communities from invasive species, insects and diseases, soil conditions (i.e. high sand or high clay content), occurrence of high ozone levels, and weather (i.e. drought with high temperatures – increase risk of wildfires). According to Mangold et al. (2003) about 1400 species of invasive plants introduced in the United States are recognized to pose significant threats to the biodiversity of forest ecosystems.

In the Southern US, pine forest composition has significantly changed over the last century. Human migration, fire suppression practices, and expanding agriculture contributed to the decimation of longleaf pine which was once the dominant specie (Mangold et al. 2003). The increased planting of loblolly pine replaced longleaf and increased the opportunity for the pine's most serious pest, the southern pine beetle (Mangold et al. 2003, and Hoffard et al. 2003). The southern pine beetle is an example of a native insect that became a pest due to forest changes. Certain circumstances, such as drought, hurricanes, and urban development can increase southern pine beetle populations (Duryea and Hermansen 2002). At endemic levels the southern pine beetle can play a critical role in the development, death, and rebirth of entire forests (Mangold et al. 2003, and Hoffard et al. 2003).

Risk of wildfires at the WUI

Over the last decades fire prevention programs combined with the advance in firefighting technology have contributed to a greater control of fire (Vicars and Luckhurst 2003). As a result, significant changes occurred in forest structure, to include the formation of a dense midstory in some mature forests that act as a fire ladder increasing the risk of wildfires (Carey and Schumann 2003, and Duryea and Hermansen 2002). Wildfires that burn at extremely high temperatures can destroy entire forests and cause damage to the soils, water quality and quantity, fisheries, plant communities, and wildlife habitat (Mangold et al. 2003). Wildfires can also increase susceptibility to insect infestations and diseases, affect the air quality through smoke, cause economic losses by property damage, and force evacuations. They may also affect the economy if tourism is important and scenic beauty is destroyed (USDA, Bureau of Land Management 2004).

Catastrophic wildfires have always been considered a threat to people, property, and to forests. The threat increases near areas with a high human population density such as at the WUI (USDA, Fire and Aviation Management 2001). Although fire may have many beneficial effects on forest health, wildfire is not desirable at the WUI, where many homes are built with little consideration of fire risk or protection in choice of materials, preventive landscaping, access to water supplies, and access for fire emergency vehicles. Also, the lack of yard maintenance, especially in the case of second homes for vacations, may allow highly flammable vegetation to grow right up to the side of homes causing a buildup of fuel loads and consequently increasing the risk of fire to people and property (Duryea and Hermansen 2002).

Between 1985 and 1994, wildfires destroyed almost 10,000 houses, and burned six millions acres of public lands in the United States. In 2000, more than 6.5 million acres burned nationwide (Nowicki 2001), and in 2002 about 7 million acres burned, causing the death of 23 firefighters (Bush 2002). These numbers reflect the importance and increasing magnitude of the problem. With the increase of the population at the wildland urban interface, protecting the people and their homes from wildfires is becoming increasingly more difficult. A management strategy to reduce the risk of a wildfire and protect the environment is needed to protect people and their homes at the WUI and preserve ecosystem health.

Management Challenges at the WUI

Major issues confronted by forest managers at the WUI include: development along the forests boundaries, the greater use of the forest, pressures from adjacent landowners, aesthetics, and public concerns, which include maintenance of tree cover, avoiding erosion, control of herbicide and pesticide use, and monitoring disturbance and discomfort caused by harvesting operations (Duryea and Hermansen 2002). Also conflicts among the landowners and community members can make the management of WUI even more complicated for forest managers. Vaux (1982) said when people are in close contact with traditional forest management practices, the potential for conflict about forest management increases (Duryea and Hermansen 2002). New landowners of smaller parcels may have a variety of objectives and attitudes that are not necessarily addressed by traditional forest management practices, and balancing those different interests is a challenge that managers at the WUI must frequently face.

Ownership Patterns

The social and economic characteristics of the private rural landowners and their objectives must be considered when managing forests at the WUI. The characteristics of rural landownership are influenced by the pressure of human population growth, the conversion of rural lands to urban areas, and constant social changes (i.e. shifts in the local economy or changes in ethnic diversity). Those characteristics are also important in planning the future of the rural landscape and in accommodating the effects of the expanding WUI (Cordell and Macie 2002). The change in ownership patterns suggest that a larger proportion of the nation’s wood supply might come from small acreage, privately owned forests (Updegraff and Blinn 2000). In the Southern US over 93% of the private ownerships have fewer than 40 hectares of forestland (Birch 1997). These owners manage about 30% of the private forestland, and according to Birch (1997), the greatest concern about forest fragmentation and rapid turnover from rural to urban areas is concentrated among them.

Ownership Objectives

Growing timber can be a profitable activity however its success depends on the facts and circumstances in each case. Forestry is a long-term investment, and landowners may receive significant revenue from timber sales only once in their lifetime. The rotation length can vary from of 20 to 30 years in plantations, to up 60 years in natural stands (Haney et al. 2001). The long investment horizons create a variety of risks that do not affect conventional investments. These risks include changes in product values, unpredicted shifts in supply and demand, changes in consumer preferences and technologies, and shifts in public policy (Haney et al. 2001).

New landowners who migrate from urban to the rural areas are common at the WUI. These new owners often have different management objectives than the previous owners and may be unfamiliar with forest management practices (Haney et al. 2001). Cordell and Macie (2002) reported that 20% of the landowners at the WUI have definite plans to sell all or part of their land in the future, 13% plan to add acreage, and 51% have no definite plans. Reasons for owing land include the direct contact with nature, enjoyment of the green environment, close contact with wildlife, maintenance of wildlife habitat, and investment (Cordell and Macie 2002). A good share of rural landowners holds forestland simply because it is part of their farm or residence and utilizes wood mainly for domestic use. According to Duryea and Hermansen (2002), 59% of landowners in the South emphasize improving wildlife, water quality, aesthetics, and other natural components in reasons for ownership. Only 4 to 7% of forest landowners consider making money the primary reason for owning their forestland (Duryea and Hermansen 2002). Despite this variety of priorities, previous studies indicated support for environmental projects by landowners and residents at the WUI, reflecting greater interest in preserving the forest health than producing income from forests (Duryea and Hermansen 2002).

WUI Forest Treatments

Active management of forests decreases the chance of large, expensive and damaging wildfires, and has the potential to restore the forest health. According to Carey and Schumann (2003) the three main factors that affect fire behavior are topography, weather, and fuels. These are called the fire environmental triangle (Pollet and Omi 2002). Topography and weather may play a more important role, but in practice fuels are the only factor that land managers can modify to reduce fire potential.

The best general approach would be managing fuel loads by managing tree density and species composition with well designed silvicultural systems (Graham et al.

1999). Silvicultural systems would include a mix of thinning, prescribed fire, and surface fuel treatments. The specific goals of fuel treatments are to reduce wildfire severity, rate of spread, intensity, and control efforts (Carey and Schumann 2003). Treatments provide opportunities for effective fire suppression and protection of high value areas. Forest fuel reduction treatments can alleviate forest health problems due to overstocking as well as the associated wildfire hazard (Conard and Hilbruner 2003).

Prescribed fire is one way of accomplishing fuel reduction, but in the modified WUI ecosystems it is impractical and may have undesirable effects (Pollet and Omi 2002). Clearcuting and conversion of pine plantations to mixed hardwood stands may be the fastest method of reducing the long term fire hazard, but public acceptance of this strategy may be low due to negative visual impacts. In addition, landowners may value the recreational and aesthetic aspects of the stand more than its economic value (Nowicki 2001). Nowicki (2001) suggested that communities can be protected from wildfires by treating a narrow strip of forest nearby the community and by treating individual houses and the surrounding properties. These practices would be more effective than treating forests at greater relative distance from the houses. In his opinion the wildland fuel characteristics beyond the home site have little importance to the losses of houses at the WUI. The creation of a defensible space can provide a potential fireline around the communities, and a safer area for firefighters to combat and contain the fires.

According to the literature, the most common techniques applied by land managers to manage fuel loads are the use of prescribed fire and mechanical treatments or thinning. Sire and Taylor (2003) synthesized over one hundred scientific publications analyzing the influence of forest structure on wildfire behavior and the harshness of its effects, and they found that thinning and prescribed burning are the two long employed techniques to maintain forest health and reduce wildfire risk. However, the proximity of populated areas to forests, a characteristic of the WUI, makes both methods more difficult to administer. The risk of prescribed fire in terms of potential liability and acceptance by neighbors may rule out its use in locations where it could be beneficial. Mechanical treatments, more specifically commercial timber harvesting, may also face problems concerning public acceptance and potential liability for contractors.

Prescribed Fire

Prescribed fire is the preferred fuel reduction treatment for stands with low to moderate tree density, little encroachment of ladder fuels, and moderately to strongly sloping terrain. It can be used to reduce dead and down fuels, live surface fuels and dead and live canopy fuels (Carey and Schumann 2003). In fire-adapted forests it is usually the least expensive method for removing combustible fuels and reducing the risk of wildfires. Rummer et al. (2003) reported a cost of US$227.00/ha for prescribed management-ignited fires. Prescribed fire can also benefit wildlife. Burning helps to control sapling hardwoods and maintains open understories favoring native plants. It also reduces the duff layer, scarifies seeds, and promotes the germination of seeds. The effectiveness and appropriateness of prescribed fire to enhance wildlife depends on the weather, initial fuel conditions, and the pattern of burning (Conard and Hilbruner 2003).

However, many public health and safety issues are associated with fire. Issues include control of prescribed fire, reduced visibility on highways due to smoke, reduced air quality, and ash drifting into swimming pools (Duryea and Hermansen 2002). Its use at the WUI may be limited by public and landowners acceptance, its potential risks to the community, smoke management regulations, and liability involved with the practice at the WUI. People may not understand its benefits to the forest or agree that its benefits exceed the risks involved with its application. Such issues make the application of prescribed fire treatment at the WUI problematic to land managers.

Mechanical Treatment

Mechanical treatment or thinning is defined as temporary reductions made in stand density in order to stimulate the growth of trees that remain and to increase the total yield of useful material from a stand (Smith et al. 1997). The goals of thinning are to redistribute the growth potential of the stand to the well-formed, high quality trees, maintain the growth rate of the stand, and utilize merchantable timber products for financial advantage (Roth 1983). Mechanical thinning is more frequently used on forests that are too dense to burn and where there are markets for small diameter trees (Pollet and Omi 2002). Thinning has the potential to alter fire behavior by reducing the flammability in the midstory and overstory while treating surface fuels. Thinning can improve forest stands, wildlife habitat, and reduce fuel loads (Sire and Taylor 2003). Thinning from below (removing the smallest trees) is generally assumed to be more effective at altering fire behavior than thinning from above (removing the largest trees). It can most effectively alter fire behavior by reducing crown bulk density, increasing crown base height, and changing species composition to lighter crowned, fire-adapted species (Graham et al. 1999). A typical fuel reduction harvest removes the entire understory, thins merchantable trees to a target basal area, and removes the slash. Such silvicultural practices have the ability to restore the health of forest stands. The nutrient removals associated with these practices do not seem to be significant when compared to the benefits gained from fuel reduction (Bolding et al. 2003).

Thinning is more effective at reducing fire hazard when followed by prescribed fire to reduce the amount of fine fuels (i.e. branches, limbs) left on the forest floor. Wildfires in recently harvested stands can be intense because of heavy fuel loads (Sanders and Van Lear 1987). If slash is not removed or treated, the resulting fuel complex increases the probability of a more intense, damaging, and extensive wildfire (Carey and Schumann 2003). Combined thinning and prescribed burning complement each other in a treatment regime to improve forest health, reduce the risk of wildfire, and reduce the susceptibility to pests and diseases. The benefits of these practices are supported by over a hundred of scientific investigations (Sire and Taylor 2003).

Even though mechanical thinning, specifically commercial timber harvesting, may hold promise as a treatment to reduce fire hazard at the WUI, it also faces problems with public acceptance. The main issue is the negative visual impact caused by harvesting operations. Additional problems such as low demand for products, difficult access to stands, and small acreage ownerships may make thinning even more difficult. The harvest of small low-value stems is usually more expensive, resulting in higher harvesting cost per unit area (Bolding 2002, Bolding et al. 2003, Rummer and Klepac 2002, and Lansky 2000). These could affect the economic feasibility of the treatments.

Other mechanical treatment options would include the use of smaller and more adapted equipment to WUI conditions. According to Jensen and Visser (2004) harvesting systems that are appropriate for operating in the urban interface have been developed by modifying existing equipment and converting agricultural equipment to forestry applications. Agricultural tractors are lighter and smaller than traditional harvesting equipment and can be adapted to be used effectively on partial harvests of small stands (Shaffer 1992). Tractor based systems are well suited for operating in small stands due to their maneuverability and low initial investment, but their low productivity may limit their use in commercial systems (LeDoux and Huyler 2000).

Economics of Mechanical Treatments at the WUI

Harvesting systems on small tracts must be cost-effective, flexible and simultaneously meet constraints regarding safety and minimal site impact. While the current generation of highly productive and capital intensive harvesting machinery is well suited for large stands, its applicability in small tracts where partial cutting is normally prescribed is limited (Updegraff and Blinn 2000). Bolding et al. (2003) reported that few productivity estimates have been assigned to mechanical fuel reduction systems. Mechanically treating stands for fuel reduction usually implies the removal of small, low-value stems which normally results in higher harvesting costs per unit area and may make mechanical treatments unattractive to loggers.

However, wood markets in the Southeast US are more favorable to mechanical thinning for wood products than other regions. The region today leads the timber market in the US, accounting for over 40% of timberland, and projections indicate that the South will continue to lead other regions in timber supply (Duryea and Hermansen 2002 and Wear and Greis 2002). Adequate markets increase the potential of mechanical thinning and encourage the exploration of alternatives to make it more economically feasible and aesthetically acceptable.

Alternatives for thinning exist to address economic, aesthetic, silvicultural, and wildlife management constraints. An example is the conversion of even-aged pine stands to uneven-aged mixed species stands. Uneven-aged management can produce a greater variety of forest products in the stands, which can be adjusted to unpredictable market changes (Baker et al. 1996). Removals occur at designated cycle times with individual tree removal distributed throughout the stand or small patch removals. In terms of public acceptance it would result in a stand with more or less continuous tree cover over time. The permanent forest cover and complex structure would also serve to enhance a variety of wildlife habitats, reduce insect outbreaks, and reduce vulnerability to wildfires (Baker et al. 1996).

Other modifications to thinning should attempt to lower harvesting costs and address long term management issues. Conventional thinning of pine may address public and management concerns in the short term, but does not address the need for continued even-aged management, eventually resulting in a clearcut. Innovations in management occur, but they mainly address real estate concerns, not forest health or long term management issues.

I suggest two alternative treatments for small acreage, high density pine plantations. The first is a first thinning that begins a transition from even-aged to uneven-aged management. Benefits of uneven-aged management in this context are described above. The second alternative is to create a two-aged stand with combinations of cut patches and leave areas. The system of patch and leave areas can be oriented to provide visual buffers. Additionally changing species composition in cut patches alters forest structure and the nature of fine fuels. Economically the increased removal volume from clearcut patches improves economic feasibility.

The objective of this project was to analyze the production and costs of these commercial thinning techniques. If the treatments can reduce the cost of treatment and satisfy public and landowner concerns, they may be valuable tools to maintain the forest health.

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II. PRODUCTIVITY ANALYSIS OF MECHANICAL THINNING TREATMENTS IN SMALL STANDS AT THE WILDLAND URBAN INTERFACE

ABSTRACT

Mechanical thinning treatments can be an alternative to treat overstocked stands in order to reduce fire hazards and to improve forest health. Their use in Wildland Urban Interface (WUI) management may be limited by the high costs involved with mechanized operations. These treatments tend to be even more costly at the WUI due to low volume stands and low value products. The main goal of this study was to analyze the productivity of conventional and heavy mechanical thinning operations. Heavy mechanical thinning at the WUI might make treatments economically feasible. The harvesting system in all locations consisted of 1 skidder, 1 feller-buncher, and 1 loader. Treatments were applied on loblolly pine 1st thinning commercial harvesting. The conventional thinning consisted of a 5th row removal followed by selection from the remaining rows, leaving a target basal area of 16m^2/ha. The second thinning, referred as heavy thinning consisted of a conventional thinning followed by a more intense selection from the remaining rows, leaving a target basal area of 9m^2/ha.

Statistical analyses revealed no treatment difference for either the skidder or the feller-buncher cycle time. Production models indicated skid distance and number of

trees per accumulation were the most significant variables affecting skidder and feller-buncher cycle times, respectively. The feller-buncher models also indicated a significant difference between row removal versus selection from the remaining rows. The results indicated a treatment effect on loader utilization with higher utilization rates for the heavy treatment. Overall the results indicated no change in system productivity due to treatment. Models were significant and similar in form to other production equations.

INTRODUCTION

The management of forest stands at the Wildland Urban Interface (WUI) introduces numerous challenges to forest managers, including potential forest health problems (wildfire, insects, and diseases), which require active management either through mechanical treatments and/or prescribed fire (Bolding at al. 2003). The proximity to populated areas, public acceptance, and potential liability for the contractors make both prescribed fire and mechanical treatments difficult to administer. Urban residents moving to a wildland interface frequently are unfamiliar with the management needs of a forest and are often intolerant of certain harvesting practices and aesthetics changes due to management of the forest (Kundell et al. 2002). When designing treatments for the WUI, forest managers should consider the likely visual impact (Duryea and Hermansen 2002). Negative events like clearcuts in visible areas could be the motivation for enacting restrictive local harvesting regulations to preserve the remaining forest cover.

Conventional thinning practices may have a low visual impact initially, but maintaining the even-aged management of the stand means that eventually a stand regenerating clearcut would be necessary. A possible solution to reduce visual impact in pine management would be the transition to uneven-aged pine management, which would require a heavier initial removal than conventional thinning. After the initial removal the stand would have more or less continuous tree cover over time with removals evenly distributed throughout the stand. The conversion would allow the regeneration of a more shade tolerant hardwood understory, allows a wide variety of management prescriptions at operational scale, and provide greater product diversity (Rummer et al. 2003). The product diversity could make the timber in the stand more marketable when one product or another is in lower demand (Updegraff and Blinn 2000). Also during the stand conversion process, permanent skid trails could be oriented to provide locations for fire lines within the stand, potentially reducing fire hazards. In long term management the conversion to an uneven-aged stand would result in a lower visual impact.

Other important considerations when choosing a thinning method are the growth response and quality of residual trees and thinning costs (Stokes and Watson 1996). Low volume removal and low demand for thinning products (i.e., pulpwood) make thinning treatments difficult to administer and to finance (Bolding et al. 2003). The most challenging aspects of making small volume stands feasible to harvest are controlling downtime between moves and minimizing the fixed costs in landing and road preparation (Wilhoit and Rummer 1999). Increasing the feasibility of mechanical treatment in small areas requires greater harvest efforts or increasing the volume removal per hectare.

This study analyzed the productivity of heavy and conventional thinning treatment. The conventional thinning treatment is a common commercial first thinning practice in the Southeast US, and the heavy thinning for transition to uneven-aged management treatment is only a variation on conventional thinning techniques with a more intense removal. The harvesting system analyzed consisted of 1 feller-buncher + 1 wheeled skidder + 1 knuckleboom loader. This system is very common in the Southeast US, and usually offers high production and relatively low harvesting costs (Brinker et al. 1996). Skilled operators, mechanically sound equipment and sufficient wood supply, stand conditions, and harvesting prescription affect the harvesting efficiency (Kluender and Stokes 1996). The conventional treatment consisted of tree thinning with a combination of 5th row removal with selection within the 2 adjacent rows on each side of the removed row. Target residual basal area was 16m^2/ha. The uneven-aged conversion or heavy treatment was basically the same method as the conventional treatment, but with a more intensive selection from the remaining rows, resulting in a lower residual basal area of about 9m^2/ha.

The primary objectives of this study were to compare the productivity from the two treatments, and generate the cycle time models for the skidder and the feller-buncher. The result should be valuable for optimizing the harvesting operations and calculating costs. Three primary hypotheses addressed these objectives:

Ho_1: Feller-Buncher productivity will be equal for the two treatments.

Ho_2: Skidder productivity will be equal for the two treatments.

Ho_3: Loader productivity will be equal for the two treatments.

MATERIAL AND METHODS

Study Area

The study was conducted in six different locations in the states of Alabama, Georgia, and Mississippi. The selection of the harvesting sites was primarily based on their thinning treatment, but also followed these considerations:

- Even-aged loblolly pine plantation;
- Similar harvesting systems;
- First thinning;
- Similar target residual basal area – around 16m^2/ha and 9m^2/ha for the conventional and heavy treatment, respectively;
- Similar topographic conditions, with slope $\leq$ 10%.

All six sites were harvested by crews utilizing similar harvesting systems composed of 1 feller-buncher + 1 wheeled skidder + 1 knuckleboom loader and 3 or 4 crew members. The feller-buncher cut the trees and placed multiple full trees in a bunch. The feller-buncher bunches were skidded to the deck area, sometimes with an intermediate stop at a delimbing gate. At the deck the trees were processed by the loader and sorted into two products, pulpwood or chip and saw.

Data Collection

Stands on all study sites were sampled to gather information on both pre and post-harvest stand conditions. In each stand a total of 10 points, pre and post-harvest, were randomly located 50 meters apart along random azimuth directions. The inventory data consisted of basal area, DBH, product class, form, and presence of fork or canker. The three product classes considered DBH, form, and merchantable height. Product class descriptions were: non-commercial pine trees DBH < 10cm; pulpwood pine trees DBH 10 – 25cm; and chip and saw and saw timber pine trees DBH > 25cm.

Height of dominant and co-dominant trees, in each harvesting site, were collected to estimate site index.

Gross Time Study

Gross time study data were collected by observation of the operation for the entire time spent on each site. Time varied from 1 to 3 days per study site. Gross time study data categories followed those from Miyata et al. (1981), and included these categories:

- Scheduled machine hours (SMH) or operator work time;
- Productive machine hours (PMH) equivalent to total machine hours minus non-productive machine hours;
- Harvest volume of truck loads – weight, wood product, and logs per load, by product class;
- Skidder cycles – total number of skid cycles and bunch size (trees skidded per cycle).

A skidder cycle started and ended when the trees were dropped at the deck. This parameter was used to calculate average skidder cycle time in minutes by dividing productive machine hours by number of skids per day. Productive machine hours or productive time referred to the machine hours where the machines were actually producing or operating (PMH = machine hours – non-productive machine time $\geq$ 10 minutes). Non-productive time or delays were recorded and separated into 4 categories:

- Mechanical delay: machine failure or maintenance (skidder stopped for repairs, refuels, over-heating, etc);

- Supervisory delay: communication among the crew, planning, and etc;

- Bottleneck delay: machine not operating due to limitations in other functions; and

- Other: any other cause of delay.

Elemental Time Study

Elemental time study information of the skidder and the feller-buncher was collected using a video camera system. The skidder activities were recorded for sample periods of 1.5 hours until approximately 50 skidder cycles were recorded on each site. The video camera system consisted of one Philips Magnavox PM61761 ColorCam Mini Wired Camera mounted inside the skidder cabin, facing the grapple (back of the skidder). The camera was connected to a Sony GV-D200 Digital8 Video Walkman VCR attached to the operator's seat. After videotaping the tapes were replayed, and the elements recorded and timed. The video walkman had an internal clock that stamped the video tape with a running time. The total time spent on each element was then computed for each element and total cycle time.

The five elements used for elemental analysis (travel empty, grapple and load, travel loaded, delays, and delimbing time - when applied) agreed with the methodology utilized by Klepac and Rummer (2000), and Lanford and Stokes (1996), and to the time study techniques developed by Gibson and Rodenberg (1975). The elements descriptions are listed below:

1 – Travel empty - skidder travels unloaded from deck to bunch in the woods; skidder starts moving toward woods; skidder begins backward movement to pick up log(s);

2 - Grapple and load – skidder begins backward movement to pick up bunch; grapple picks up bunch; skidder starts forward movement;

3 – Travel Loaded - skidder travels either partially or full loaded to the next location for log pick up or towards the deck; skidder begins forward movement carrying a partial or full bunch; skidder drops opens the grapple to pick up another bunch or to drop the full load at the deck and end the cycle;

2 – Grapple and reload – grapple drops partial load; grapple picks up log(s); skidder starts forward movement;

4 – Delimbing - skidder moves backwards, towards the delimbing gate or standing trees; skidder starts forward movement;

5 – Delays or Downtime – downtime of less than 10 minutes of duration, between elements 1 and 4.

The skid distance traveled in a cycle was obtained using global positional system (GPS) information. A GPS unit, model Garmin GPS 12XL equipped with a remote antenna, was placed inside the skidder cabin. The units were located in a place that did not interfere on the operator’s movements and the antennas in a position to best capture the satellite signals. The Garmin GPS 12XL was set on the “Track” feature, option “Fill”, recording the skidder location every 30 seconds. The “Fill” option meant that the GPS recorded track points until the unit reached its memory capacity (about 1000 points a day). At the end of each day the GPS information was downloaded, and the text files imported to Microsoft Excel. Spreadsheet formulas calculated skid distance of each cycle based on the deck location. The deck area was mapped by collecting four GPS “waypoints” (waypoint is a specific point location saved in the receiver’s memory) around its boundaries, forming a polygon. The center of the deck was determined by collecting a waypoint at the middle of the deck. The skidder distance position was calculated in three different ways from the latitude and longitude coordinates. Skid distance 1 was calculated by adding all the distances between track log points, to the furthest point from the deck (one-way trip); skid distance 2 was calculated by adding all the distances between track log points till the cycle ended/started (round-trip); and skid distance 3 was the distance in meters between the center of the deck and the furthest point from the deck.

For the feller-buncher, the elemental time study utilized the same video camera system used on the skidder. The camera was located inside the cabin facing the saw head (front of the feller-buncher). Elemental time study technique utilized by Keatley (2000) was applied to the feller-buncher when collecting individual cycle times. A feller-buncher cycle consisted of the feller-buncher traveling to a tree(s), grabbing and cutting the tree(s), traveling back to the skid trail, and swinging and placing the tree(s) (Lanford and Stokes 1996, and Greene et al. 1987). A cycle ended/started with the swing and place element. About 30 feller-buncher cycles were tape recorded on each site, 15 on a row thinning and 15 from selection from the remaining rows. The elements and their definitions are listed below:

1 - Travel to tree – feller-buncher begins moving towards the 1st tree(s) of the cycle or accumulation to be cut; feller-buncher reaches the 1st tree and starts swing element;

2 - Swing, grab, and cut – feller-buncher operator swings feller-buncher head to grab the tree(s); feller-buncher head grabs and cuts the tree(s); feller-buncher accumulates the tree and starts movement towards the next tree or bunch;

3 - Travel with tree – feller-buncher begins moving towards the next tree(s) to be cut on the cycle or to a new or existing bunch; feller-buncher reaches the next tree or bunch and starts the swing element;

4 - Swing and place – feller-buncher operator swings the feller-buncher head and places the accumulated tree(s) on the ground on a new or existing bunch, ending the cycle; and

5 – Delays or Downtime – any activity other than the above.

After videotaping, the tapes were replayed and watched, and the elements recorded and timed. The total time spent on each element and the total cycle time were recorded.

Productivity data were also collected on the loader, by field observation using work sampling technique (Miyata et al. 1981). Work sampling information was collected on the loader throughout the entire time spent in the field for data collection. Work sampling time sheets were generated with random numbers for each instantaneous observation considering daily shifts of 10 hours, in a maximum of 30 observations per day.

Data Analyses

Data analyses used graphs and statistical tools to identify trends of elemental and total cycle times with measured variables. Multiple linear regression analysis was used to generate the models for total cycle times and elemental times for the skidder and the feller-buncher. Statistical Analysis System (SAS System for Windows V8.2 1999-2001) was used to perform the analyses. Dummy variable techniques were used to examine differences in qualitative conditions and among the harvesting sites. Stepwise selection technique for multiple regressions was used to identify the factors affecting machine performance and to select the best model for each element and total cycle times. Stepwise selection rejected variables when p-value ≥ 0.15. Residual plots were used to check the normality of distribution in each generated model. Tables 2.1 and 2.2 show the variables used to generate the models for feller-buncher and skidder cycle time and the elements.

RESULTS AND DISCUSSION

Gross Time Study

Table 2.3 shows the stand parameters and the results of the treatments. On average the feller-buncher removed 56% of basal area on conventional thinning and 72% on heavy thinning. The age of the loblolly pine plantations ranged from 13 to 25 years. Site number 6 was the oldest and had largest trees and most chip and saw. Table 2.4 displays the equipment used in each phase of the operation. The most significant difference was delimbing technique among the sites

Work Sampling – Loader

The work sampling information collected for the loader is summarized on Table 2.5. The number of working hours varied but was always near 10 hours per shift. A total of 270 observations were collected, where 68% of observations were considered productive time and delay time accounted for the remaining 32%. The percentage of productive time observations was considered the loader utilization rate. Delay time included mechanical, supervisory, and bottleneck delays, and other (any other activity where loader was not being productive). Mechanical delays were the most frequent with 37% of total delay time. Loading and slashing/delimbing time together accounted for approximately 65% of productive time. Productive time also included the activities of sorting, cleaning, and moving logs. Loading time referred to the times where the loader was actually loading a trailer, slashing/delimbing time referred to delimbing time through the pull-thru delimber or the chamber delimbinator (sites 4 and 5), sorting referred to sorting logs by product class or species, and moving logs referred to moving logs onto or between piles.

Statistical analysis indicated significant difference between treatments, with higher machine utilization rate for the heavy thinning. A regression model based on the work sampling information estimated utilization rate (UR) as a function of treatment:

$UR = 81.6 - 24.1 * trt$

F-value = 18.64; p-value < 0.0019; $R^2 = 0.67$; N = 11; and MSE = 85

Where:

UR = utilization rate (%);

trt = dummy variable for treatment (trt = 1 for conventional and trt = 0 for heavy).

There may be several explanations for the treatment difference indicated by the model. First, UR was estimated over a short period of time and utilization rates may be higher or lower than long term averages. For example delay time differences on sites 4 and 6 found no bottleneck or supervisory delays. The differences between treatments also may be explained by the fact that 2 of the 3 heavy thinning sites used the chamber delimbinator, and the 3rd was the harvesting site with the larger trees. The chamber delimbinator and the larger trees could have increased the work load of the loader per unit volume.

Elemental Time Study – Skidder

A total of 297 cycles were collected on the skidders. Table 2.6 summarizes the time study and the observed independent variables. Other independent variables included in the analyses were the dummy variables for treatment and variable interactions (between the independent variables skid_dist2 and trees/bunch, and the independent variables and logging sites).

Skidder total cycle time had a mean of 6.26 minutes without delimbing and 6.46 with delimbing element. Stepwise selection with only skid distances selected skid distance 2 (sk_dist2; p-value < 0.0001) from the three variables for skid distance. That was the reason for including only skid distance 2 in the skidder total cycle time and element models. Limiting models to one variable of skid distance made interpretation of models more straight forward. Mean total skid distance 2 was 462 meters (round trip), with a range of 17 to 1372 meters. Overall, the harvesting sites had similar range in skid distance.

Skidder Elemental Equations

Regression equations were developed for the elements travel empty, grapple and load, travel loaded, delay, and delimbing. Table 2.7 has the selected models for the skidder and the feller-buncher elements. Element times are estimated in seconds per cycle. Residual plots for the total skidder and feller-buncher cycle time and element models confirmed the assumption of normality of error for all the generated models.

Travel empty and travel loaded had means of 1.59 and 2.16 minutes, respectively (Table 2.6). Mean travel empty was longest on site 4 and shortest on sites 2 and 6. Average travel loaded varied for all sites. Skid distance was the most significant single variable in the model for travel empty and travel loaded times. Travel times increased with higher skid distance. Tufts et al. (1988) also found skid distance to be the most significant variable for travel time. Interactions of skid distance and harvesting site appeared in all but the delay element model. These interactions may have adjusted the models for differences in element times as a function of skid distance, and for operator and operation differences.

The element grapple and load had a mean time of 1.21 minutes. Mean grapple and load was most affected by bunch size, where the model suggested longer elements for larger bunches. It took more time to accumulate larger bunches (Tufts et al. 1988). Grapple and load time was longer for sites 2, 5, and 6.

Delay time appeared in only 213 of the 297 cycles, and on the other 64 cycles delay time was equal to zero. The mean delay time was 1.80 minutes and mostly represented cleaning activities on the deck area (i.e. removing slash, or cleaning the delimbing gate area). The selected delay time element model indicated a treatment difference as an interaction with skid distance, with higher delay time for conventional thinning at short skid distances and lower delay time at long skid distances. Since delay time mostly represented deck operations, cycles with longer the skid distance were less likely to face bottlenecks at the deck.

Skidder Total Cycle Time Equation

Stepwise selection of total skidder cycle time without delimbing ($CC_{SK}1$) returned the following equation:

$$CC_{SK}1 = 171.934 + 0.179*Sk\_dist2 + 0.0116*skntrees + 0.0883*sks4 + 0.1477*sks5 + 0.0458*sks3$$

F-value = 55.82; p-value < 0.0001; $R^2 = 0.49$; N = 297; and MSE = 10906

Where:

$CC_{SK}1$ = total skidder cycle time (in seconds);

Sk_dist2 = total skid distance on a cycle (round trip in meters);

Skntrees = interaction Sk_dist2*number of trees/cycle; and

Sks*i* = interactions Sk_dist2*harvesting site (*i*), and s*i* is a dummy variable for logging site *i* (*i* = logging site 1 to 6)

Total skid distance and the interaction of skid distance and the average number of trees/bunch were prominent in the total cycle time model. Skid distance is commonly the most, if not the only significant variable affecting total cycle time (Tufts et al. 1988, Lanford and Stokes 1996, Kluender and Stokes 1996, Brinker et al. 1996, Kluender et al. 1997, and Keatley 2000), but others have also indicated that bunch size significantly affects skidder cycle time. No treatment effect was indicated by the selected model for total cycle time.

Figure 2.1 represents the effect of skid distance and skntrees on skidder total cycle time. The sample total cycle times generated were based on the median, 1st and 3rd quartile values for variables skid distance and skntrees (415, 271, and 590 meters, and 13.3, 18.2, and 19.5 trees, respectively). Total cycle time increased with both increasing skid distance and bunch size (skntrees). Total cycle time increased 28.3% within the skid distance range displayed, while it varied 15.0% within the range of skntrees.

Delimbing Element Equations

The gate delimbing element had a total of 131 observations, appearing in only three of the six harvesting sites (2 conventional and 1 heavy thinning). Delimbing time had a mean of 0.39 minutes or 23 seconds and corresponded only to the time when the skidders were backing up and pushing trees through the delimbimg gate or standing trees. Cleaning the delimbing gate was included as delay time. The model for delimbing element time is shown on Table 2.7. The dummy variable for treatment effect (trt) and the variable for bunch size (ntrees) significantly affected delimbing time. The first indicated longer delimbing times for heavy thinning. However, delimbing time only occurred in one heavy thinning site, site 6, with the oldest plantation and the largest trees which likely affected delimbing time. The presence of the variable ntrees in the model suggested a slight increase in delimbing time as bunch size increased (Tufts et al. 1988).

The model for total cycle time with delimbing time was derived from the sites that had gate delimbing as part of the cycle (sites 1, 3, and 6). Stepwise selection indicated the following model as the best to predict total cycle time with delimbing.

$CCd = 159.29278 + 0.37611*Sk\_dist2 + 0.0498*sks3$

F-value = 237.22; p-value < 0.0001; $R^2 = 0.64$; N = 297; and MSE = 8136

Where:

CCd = total cycle time with delimbing time included (in seconds)

Again skid distance was the single variable that most significantly affected total cycle time. Delimbing time (DL) can also be added to the skidder total cycle time equation ($CC_{SK}1$) by adding the element equation for delimbing, when applied. Gate delimbing represented approximately 3% on total cycle time, compared to 17% found by Brinker et al. (1996).

Elemental Time Study – Feller-Buncher

A total of 195 cycles were measured on the feller-buncher. The feller-buncher time study and measured variables used to generate the cycle time and elements models are summarized on Table 2.8. Other independent variables included in the feller-buncher analyses were the dummy variables for treatment (trt) and for thinning method (met), and variable interactions (between the independent variable for trees/cycle and the dummy variables for logging sites). Distances were not measured for the feller-buncher cycles. Feller-buncher total cycle time had a mean of 1.06 minutes. The average feller-buncher accumulation was 4.7trees/cycle. The skidder pulled on average 16.5trees/cycle which resulted in 3.5feller cycles/skidder cycle.

Feller-buncher Elemental Equations

The elements travel to tree, grab and cut, travel with tree, and swing and place trees were present in all the 195 feller-buncher cycles. The elements means were 0.22 minutes (13 seconds) for travel to tree, 0.18 minutes (11 seconds) for grab and cut, 0.52 minutes (31 seconds) for travel with tree, and 0.14 minutes (8.4 seconds) for element swing and place. The elements grab and cut and travel with tree usually had more than one observation per cycle with the number of grab and cut elements indicating the number of trees cut in a cycle. Regression equations were developed for each of these elements. Observed delays were infrequent and short and were not subjected to analysis. Table 2.7 shows the models generated for the feller-buncher cycle elements.

No treatment effect was detected in any of the elements. Thinning method was the single variable that most significantly affected feller-buncher total cycle time, being present in all the element equations. Interaction of trees/cycle and harvesting site also appeared in all the element models. That probably adjusted the models to number of trees cut in a cycle (accumulation size) differences among the sites. These differences were indicated by a multiple range test, which revealed that the accumulation size (ntrees - number of trees per cycle) was significantly different among all the logging sites. Number of trees per cycle or accumulation size had a mean of 4.7trees/cycle. Similar to Keatley (2000), accumulation size increased travel with tree and grab and cut element times. This is a logical result since a cycle almost always included more than 1 tree. For the elements travel to tree and travel with tree, times were longer on sites 1, 3, and 4 as a function of number of trees per cycle. On sites 1 to 4, grab & cut element were longer in comparison to the remaining 2 sites, and for the element swing and place all sites had different times. Overall, site number 2 had the shortest mean cycle time and site number 3 had the longest mean cycle time. The shortest cycles on site 2 may be explained by the fact that it was the only site utilizing a three wheeled feller-buncher which may be easier to maneuver and more suitable to thinning operations on overstocked stands.

A statistical difference between thinning methods was also indicated, and overall selection thinning method increased total cycle time. Selection thinning cycles were 38% longer than row thinning cycles (Lanford and Stokes 1996, and Greene et al. 1987). The element swing and place was the only element that indicated a significant reduction for the selection thinning compared to row thinning, all the others indicated an increase on cycle time for the selection thinning. The mean cycle times were 1.23 minutes and 0.89 minutes for the selection thinning and the row thinning, respectively.

Feller-buncher Total Cycle Time Equations

Stepwise selection and two-way interactions resulted in the total feller-buncher cycle time (CC1) model:

$$CC_{FB}1 = 15.411 + 9.456*Met + 7.6938*ntrees + 2.2461*s3ntrees - 0.9831*s2ntrees + 1.5784*s1ntrees + 0.4388*s6ntrees + 0.7998*s4ntrees$$

F-value = 553.7; p-value < 0.0001; $R^2 = 0.66$; N = 195; and MSE = 324

Where:

$CC_{FB}1$ = total feller-buncher cycle time (in seconds);

Met = dummy variable for thinning method; selection = 1/ row = 0;

Ntrees = number of trees cut in a cycle; and

S*i*ntrees = interaction logging site*ntrees.

This model explained 66% of the variation of feller-buncher cycle time. The model indicated that selection thinning method increased cycle time. Cycle time also increased as the number of trees cut in a cycle increased. No treatment effect was indicated by the selected model for total cycle time.

System Productivity

Harvesting system productivity for each site was estimated using the models for the skidder and the feller-buncher cycle time without the site interactions (Sks*i* and S*i*ntrees). Site interactions were left out of the models to eliminate operator differences among sites. The average productivity of the loaders was estimated with the gross production information (see Table 2.5). Figure 2.2 represent the estimated productivity for the skidders as a function of skid distance. The feller-buncher productivity (Figure 2.3) refers to the productivity on the selection thinning from the remaining rows as a function of the number of trees per cycle.

In general the skidder productivity curves were similar, with lower productivity with the increase in skid distance. Feller-buncher curves were similar, with increasing productivity with increasing in accumulation size. Curves had different shapes due to differences in volume/tree among the harvesting sites. Overall the harvesting systems were balanced between the feller-buncher and the skidder in most sites, except for sites where the loader was limiting. On site 2, the skidder and the feller-buncher had similar range of productivity and the loader was not a limiting factor, so the system was balanced. On the other sites skidder and feller-buncher productivity could be balanced within the range of skid distance and accumulation size. On site 5, skidder and feller-buncher productivity could be balanced for skid distances up to 400m and accumulations of 4trees/cycle. On few sites (sites 2, 5, and 6) the loader would be limiting productivity at short skid distances and the skidder would be the limiting at longer skid distances.

CONCLUSIONS

The statistical analyses indicated that the heavy treatment increases loader utilization, but site differences may be the factor influencing that result. There was no treatment effect on the total cycle times for the skidder or the feller-buncher. Treatment effect was detected for delimbing elemental equations only, and it also could be related to stand/system variation. The cycle time equation for the feller-buncher ($CC_{FB}1$) indicated longer cycle times for selection from remaining rows versus row removal. The number of trees per cycle or accumulation (ntrees) also affected feller-buncher cycle time. For the skidder, the most important variable significantly affecting skidder cycle time was skid distance. Longer skid distances yielded longer cycle times. Increased number of trees per skidder accumulation also increased cycle time. In general both total cycle time models were highly significant and contained common parameters for the skidder (Kluender et al. 1997, Brinker et al. 1996, Kluender and Stokes 1996, Lanford and Stokes 1996, and Tufts et al. 1988), and the feller-buncher (Keatley 2000).

Overall I found no change in productivity due to treatment. To the extent that operations can be adjusted for small acreages, the feller-buncher productivity can be increased by increasing row removal and optimizing trees/accumulation. Skidder production is of course enhanced by shorter skid distances. Real reduction in harvesting cost on small acreages could come through efficiently organizing the operation.

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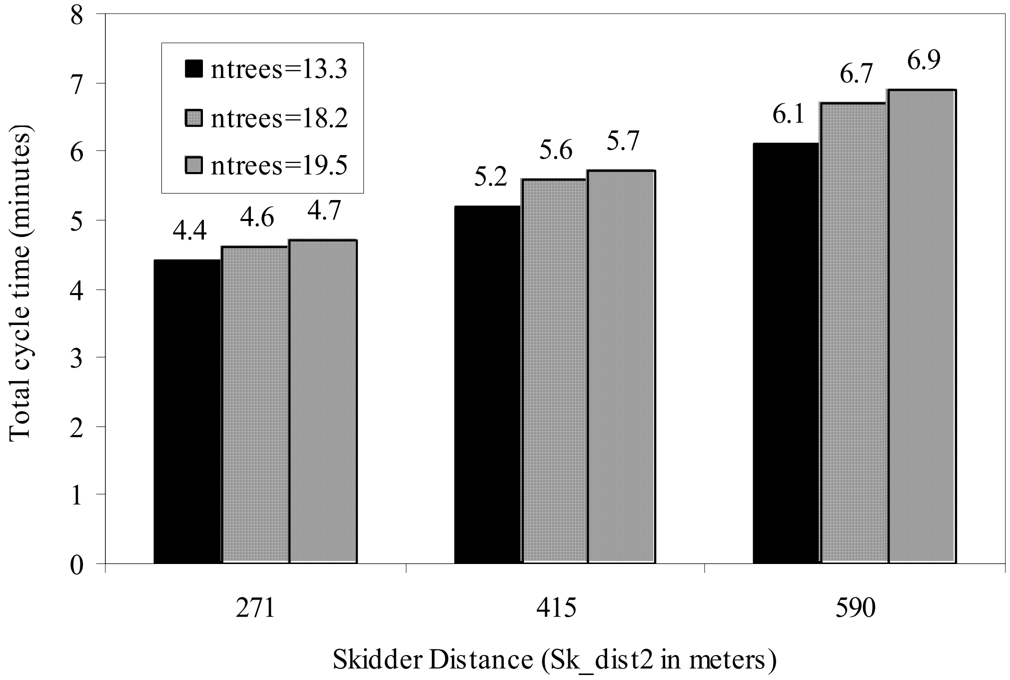

Figure 2.1. **Skidder total cycle time as a function of Sk_dist2 and skntrees. Sk_dist2 and ntrees equal 1st, median, and 3rd quartile. Site interactions were 0.**

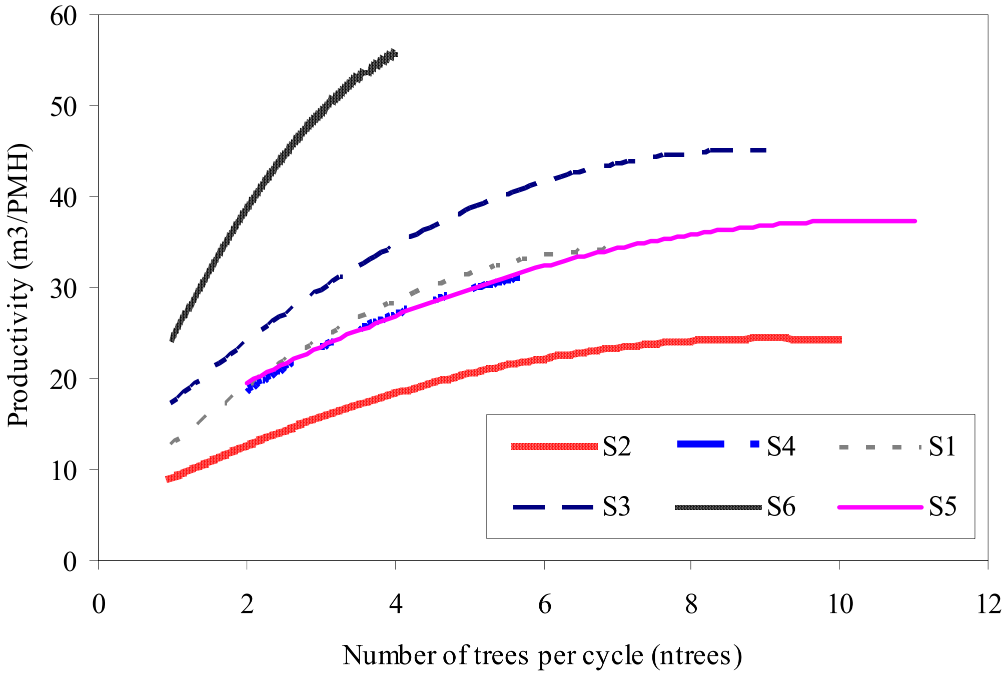

Figure 2.2. **Skidder productivity as a function of Sk_dist2 for each harvesting site (S*i*). Values for the equation were ntrees (S1=15.93, S2=27.99, S3=11.04, S4=18.2, S5=19.5, and S6=7.5) and Sks*i* (s*i*=0).**

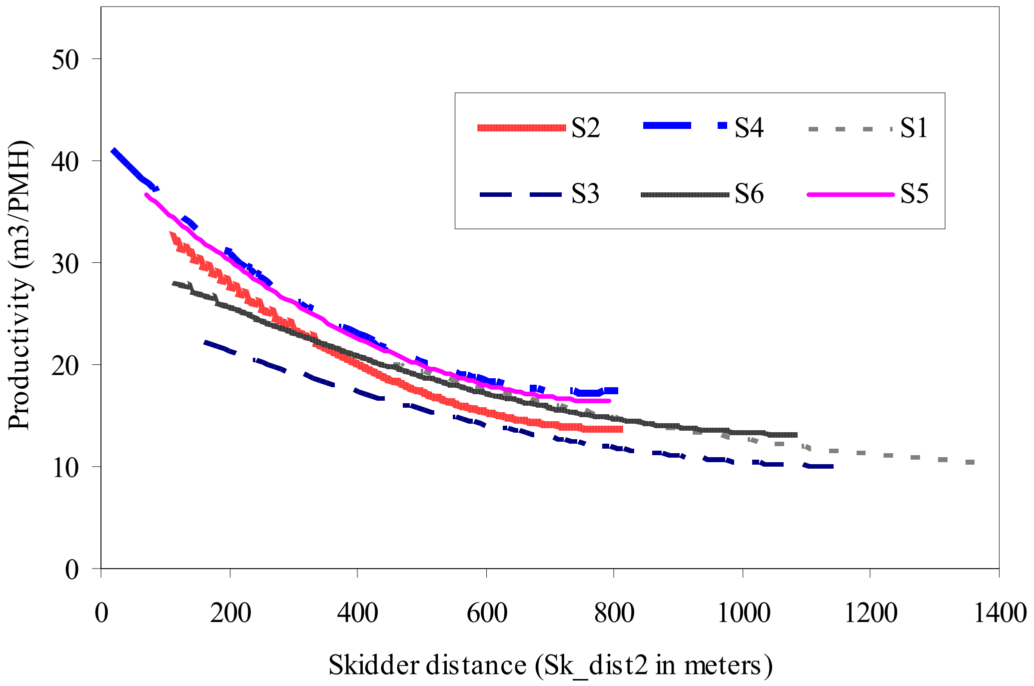

Figure 2.3. **Feller-buncher productivity as a function of ntrees for each harvesting site. Values for the equation were met (met=1=selection thinning) and s*i*ntrees (s*i*=0).**

Table 2.1. Feller-buncher independent/dependent variables.

Dependent Variables	**Description**
Time	Time (s) of each element within the cycle
CC	Total cycle time (s)
Independent Variables	**Description**
Treatment	Dummy variable for treatment; conventional = 1/ heavy = 0
Ntrees	Number of trees cut in a cycle
Si	Dummy variable for logging site i (i = logging site 1 to 6)
DBH	Average DBH of the site (cm)
Met	Dummy variable for thinning method; selection = 1/ row = 0
S*i*ntrees	Interaction logging site*ntrees

Table 2.2. Skidder independent/dependent variables.

Dependent Variables	**Description**
Time	Time (s) of each element within the cycle
CC	Total cycle time (s)
Independent Variables	**Description**
Ntrees	Average number of trees/bunch (daily basis)
Treatment	Dummy variable for conventional = 1/ heavy = 0
SK_dist	Skid distance till the furthest point off deck
SK_dist2	Total skid distance on a cycle (round trip)
SK_dist3	Skid distance to the furthest point off deck
Si	Dummy Variable for logging site i (i = logging site 1 to 6)
Sktrt	Interaction of Sk_dist2*treatment
Skntrees	Interaction of Sk_dist2*ntrees
Sksi	Interaction of Sk_dist2*logging site

Table 2.3. Stand characteristics from the 6 study sites.

Site	Location	Age Yrs	S. I. 25 (m)	Product Class (%)		Trees /ha	BA pre cut	BA post cut	Vol/ Tree
				PW	CNS				
1	Alabama	18	18.3	81	19	1102	29.4	14.2	0.11
2	Alabama	14	19.8	97	3	1849	32.6	17.0	0.07
3	Alabama	18	18.3	93	7	1683	43.6	14.9	0.13
4	Mississippi	13	19.8	95	5	1318	32.6	8.5	0.10
5	Mississippi	14	21.3	93	7	1834	38.8	10.1	0.11
6	Georgia	25	17.4	43	57	813	34.2	10.2	0.22

BA = basal area (m^2); CNS = chip and saw; PW = pulpwood; Vol/tree = volume per tree (m^2)

Table 2.4. Equipment used for each operational phase for each harvesting site.

		Equipment			
Site	Treatment	Skidder	Feller-Buncher	Loader	Delimbing
1	Conventional	Timberjack 450C	Hydro-AX 411EX	Barko 160D	Delimbing gate
2	Conventional	Timberjack 460D	Valmet 603	JD 435II	Pull-through delimber
3	Conventional	John Deere 648E	Hydro-AX 611E	Prentice 210D	Delimbing gate
4	Heavy	Tigercat 620	Tigercat 720D	Prentice 310E	Chamber Delimbinator
5	Heavy	Tigercat 630	Hydro-AX 470	Prentice 280	Chamber Delimbinator
6	Heavy	Cat 525	Timberjack 840	Tjack 330	Delimbing gate

Table 2.5. Loader work sampling results for each site.

Elements	**Site 1**	**Site 2**	**Site 3**	**Site 4** **%**	**Site 5**	**Site 6**	**Average**
Loading	27	23	21	25	10	40	24
Slash/Delimbing	18	17	17	21	27	20	20
Sorting	2	11	9	21	17	6	11
Cleaning	0	0	4	18	7	4	5
Moving logs	12	8	2	6	7	10	8
Subtotal	**59**	**60**	**53**	**91**	**68**	**80**	**68**
Delays				**%**			
Mechanical	16	6	9	9	23	10	12
Supervisory	8	8	17	0	3	0	6
Bottleneck	8	18	7	0	3	0	6
Others	9	8	14	0	3	10	2
Subtotal	**41**	**40**	**47**	**9**	**32**	**20**	**32**
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Utilization Rate (UR - %)	**59**	**60**	**53**	**91**	**68**	**80**	**68**
Production (m^3/PMH)	**14.7**	**25.7**	**16.5**	**18.3**	**25.9**	**27.2**	**21.4**

Table 2.6. Means for skidder elements, independent variables, and total cycle time (without delimbing) for each harvesting site. Numbers in parentheses are standard errors.

Time Study Variables	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Travel empty (min)	3.06 (0.20)	0.79 (0.05)	2.03 (0.14)	1.34 (0.11)	1.36 (0.09)	0.98 (0.07)
Grapple & load (min)	0.95 (0.08)	1.74 (0.09)	0.68 (0.05)	0.93 (0.07)	1.95 (0.15)	1.04 (0.08)
Travel loaded (min)	3.25 (0.16	1.68 (0.08)	2.45 (0.14)	1.93 (0.12)	1.94 (0.08)	1.74 (0.10)
Delay (min)	1.52 (0.17)	2.69 (0.61)	2.07 (0.38)	1.62 (0.23)	1.17 (0.17)	1.72 (0.20)
Delimbing (min)	0.31 (0.03)	- -	0.40 (0.05)	- -	- -	0.44 (0.03)
Cycle time (min)	8.21 (0.13)	6.07 (0.13)	6.78 (0.17)	5.70 (0.10)	6.64 (0.09)	5.34 (0.11)
Number of cycles	45	46	50	62	48	46
Independent Variables						
Skid_dist 2 (meters)	841 (18.1)	361 (7.9)	562 (15.9)	359 (9.5)	378 (6.9)	427 (12.8)
Trees/bunch	16.0 (0.6)	27.5 (1.1)	11.0 (0.5)	18.2 (0.8)	19.5 (1.0)	7.5 (0.3)
Vol/bunch (m^3)	1.9 (0.1)	2.1 (0.1)	1.4 (0.1)	2.1 (0.1)	2.1 (0.1)	1.6 (0.1)

Table 2.7. Selected models for the skidder and the feller-buncher elements (in seconds/cycle).

Skidder	**Model (N = 297)**	**F-value**	**P-value**	**R^2**	**MSE**
Travel empty (TE)	TE = 14.158 + 0.796*Sk_dist2 – 0.095*sks2 – 0.095*sks6 + 0.024*sks4 [1]	217.65	<0.0001	0.73	1209
Grapple & load (GL)	GL = 38.43 + 0.026*sktrt – 23.95*trt + 1.631*ntrees + 0.161*sks5 + 0.120*sks2 + 0.060*sks6	71.07	<0.0001	0.40	1747
Travel loaded (TL)	TL = 31.26 + 0.990*ntrees + 0.291*Sk_dist2 – 0.008*Skntrees + 0.096*sks4 + 0.058*sks5 + 0.056*sks2 – 0.0685*sks6 + 0.013*sks1	273.33	<0.0001	0.73	763
Delay (DY)	DY = 107.71 + 97.53*trt – 0.107*sktrt (N=213)	6.07	0.003	0.06	13261
Delimbing (DL)	DL = 23.24 + 0.001*skntrees -5.864*trt – 0.0163*sks1 **(N=131)**	3.51	0.017	0.08	233
Feller-buncher	**Model (N = 195)**	**F-value**	**P-value**	**R^2**	**MSE**
Travel to tree (TT)	TT = - 7.098 + 0.785*DBH + 2.411*Met + 2.411*s3ntrees + 0.497*s1ntrees + 0.176*s4ntrees [2]	85.58	<0.0001	0.18	122
Grab & cut (GC)	GC = - 3.663 + 0.158*DBH + 1.396*Met + 2.031*ntrees + 0.300*s3ntrees + 0.034*s2ntrees + 0.445*s1ntrees + 0.0431*s4ntrees	640.34	<0.0001	0.69	13
Travel with tree (TW)	TW = - 2.809 + 0.268*DBH + 6.349*Met + 5.675*ntrees + 1.011*s3ntrees – 0.891*s2ntrees + 0.474*s1ntrees + 0.566*s4ntrees	438.11	<0.0001	0.61	171
Swing & Place (SP)	SP = 7.875 – 0.769*Met + 0.301*s3ntrees – 0.0746*s2ntrees + 0.078*s1ntrees + 0.024*s6ntrees - 0.062*s4ntrees	180.96	<0.0001	0.35	13

[1] Sks1, sks2, sks4, sks5, and sks6 = interactions Sk_dist2*harvesting sites

[2] S1ntrees, s2ntrees, s3ntrees, s4ntrees, s5ntrees, and s6ntrees = interactions harvesting sites*ntrees

Table 2.8. Means for feller-buncher elements, independent variables, and total cycle time for each harvesting site. Numbers in parentheses are standard errors.

Time Study Variables	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Travel to Tree(min)	0.30 (0.05)	0.12 (0.03)	0.32 (0.03)	0.20 (0.02)	0.13 (0.2)	0.27 (0.05)
Swing & Cut(min)	0.27 (0.02)	0.16 (0.01)	0.24 (0.02)	0.13 (0.01)	0.18 (0.02)	0.10 (0.01)
Travel w/ Tree(min)	0.62 (0.04)	0.29 (0.03)	0.80 (0.07)	0.54 (0.06)	0.58 (0.06)	0.35 (0.03)
Swing & Place(min)	0.15 (0.01)	0.10 (0.01)	0.23 (0.03)	0.10 (0.01)	0.13 (0.01)	0.14 (0.01)
Total Cycle Time (min)	1.33 (0.08)	0.66 (0.05)	1.58 (0.09)	0.98 (0.07)	1.02 (0.07)	0.85 (0.06)
Number of cycles (n)	30	40	33	31	30	30
Selection (n)	15	15	18	16	15	15
Row (n)	15	25	15	15	15	15

Independent Variables						
Average DBH (cm)	20.6 5-39👽 (0.5)	17 6-26👽 (0.4)	19 10-26👽 (0.2)	19 8-27👽 (0.3)	18 7-28👽 (0.3)	27 9-42👽 (0.5)
Trees/cycle	3.8 1-7👽 (0.3)	4.5 1-10👽 (0.3)	4.4 1-9👽 (0.3)	3.3 2-6👽 (0.2)	5.3 2-11👽 (0.4)	2.4 1-4👽 (0.1)
Range in Vol/cycle (m^3/ha)	0.48 0.11-0.79👽 (0.05)	0.39 0.07-0.72👽 (0.04)	0.66 0.14-1.22👽 (0.05)	0.40 0.21-0.62 👽 (0.03)	0.63 0.21-1.16 👽 (0.05)	0.57 0.22-0.87 👽 (0.04)

III. COST ANALYZIS OF MECHANICAL THINNING TREATMENTS IN SMALL STANDS AT THE WILDLAND URBAN INTERFACE

ABSTRACT

Mechanically treating small acreage stands for fuel reduction purposes at the Wildland Urban Interface (WUI) requires careful analysis of the economics involved with the practice. The high operational and moving costs allied with the low value wood products and lower volumes per timber sale removed usually produces high harvesting costs per unit area. The economy of a tract size, the wood product to be extracted, and the volume of wood available are decisive points on examining the profitability of harvesting small tracts.

This study intended to compare three variations of commercial mechanical thinning, the conventional thinning, a heavy removal thinning, and a patch removal thinning treatments. Treatments productivity and harvesting costs were compared across three different harvesting sites and three different stand sizes (4, 8, and 12 hectares). Results indicated that skidder productivity was affected by site differences and by stand size, due to longer skid distances. Feller-buncher productivity was affected by treatment and tree size. Treatment also affected harvesting costs, with the highest costs associated with the conventional treatment and lowest costs for the heavy treatment. Patch and heavy treatment costs were very similar. Stand size differences were important because of the fixed move in costs. Harvesting costs were highest for the 4ha stands. Site

differences affected harvesting costs due to differences in tree size and consequently the value of the wood product. Treatment effects were most important at the smallest stand size, where the largest difference in residual value occurred between the conventional and heavy treatments. Results indicated that landowners could benefit from either of the alternative treatments, especially in the smallest stand, where these treatments may make harvesting more attractive.

INTRODUCTION

Sometimes loggers are asked to cut low volumes of poor-quality wood or take special care to avoid damage to residual trees. Special care generally results in higher costs and lower profit. Treatments at the Wildland Urban Interface (WUI) are likely to epitomize these situations. Providing managers with good information regarding costs may help them make decisions concerning alternative treatments for WUI management.

The profitability of a harvest involves a variety of factors including stand volume, skid distance, tree size, product value, and harvesting system (Hoffman 1991). Few cost and productivity studies concerning mechanical thinning treatments at the WUI have been done (Bolding and Lanford 2001). Small diameter material usually has little product value that can be used to counterbalance harvesting costs associated with their removal (Rummer and Klepac 2002). Harvesting small stems using fully mechanized systems is usually expensive and results in high costs per unit area (Bolding et al. 2003), and many small diameter fuel treatments are breakeven at best (Rummer and Klepac 2002).

Tract size is crucial when analyzing the profitability of a harvest at the WUI. Harvesting small parcels potentially means lower volumes per timber sale (Kittredge et al. 1996). Tract size is important since the fixed costs of moving and setting up a harvesting system must be allocated to the volume removed (Cubbage 1982). Large and mechanized harvesting systems usually have high moving and set up costs and therefore need larger volume or harvest areas to spread out fixed costs (Cubbage 1982). According to Wilhoit and Rummer (1999) fully mechanized large-scale harvesting systems are not suitable to harvest small, low-volume stands, because of the high moving costs involved and landowner concerns about site impacts. Kittredge et al. (1996) reported that a minority of the loggers surveyed would agree to harvest a hypothetical low-value 8ha stand. Cubbage (1982) reported that even if higher rates were being paid, harvesting tracts smaller than 8 to 12ha would probably not be worth the increase in harvesting costs per unit volume.

Growth of the WUI into forested landscapes means that attempting to solve these economic issues become more important to both the timber supply and forest health. The choices for addressing these issues are to either increase volume or value of removal or to lower harvesting cost. The objectives of this study are to: 1) compare harvesting productivity and costs of treatments designed to lower costs and increase volume removal and 2) evaluate changes in residual value with respect to treatment, stand type, and stand size.

MATERIAL AND METHODS

Study Area

I selected three harvesting sites where I collected production data examples of the range of conditions that might be confronted at the WUI (Table 3.1). The "small tree" site was a high density plantation with low volume per tree. The "medium tree" site had similar density but with a higher volume per tree. These two sites represent the majority of first thinning conditions operators usually face. The third site or "large tree" site was a deferred first thinning with lower density and higher volume per tree. The higher value product, chip and saw, had the greatest volume on the large tree site.

The inventory information was obtained from sample plots established on the harvesting study sites. A total of 10 points, pre and post harvest, were randomly located 50 meters apart, along random azimuth in each of the sites. Height of dominant and co-dominant trees were collected to estimate site index. Product class diameters were: non-commercial pine trees with DBH < 10cm; pulpwood pine trees with 10 – 25cm DBH; and chip and saw trees with DBH > 25cm.

Mechanical Treatments

This study compared two modified mechanical thinning treatments to a conventional thinning treatment. The conventional treatment is a common commercial first thinning in the Southeast US. It consisted of a 5th row removal with selection within the two adjacent rows on each side of the removed row or take row. Target residual basal area was $16 m^2$/ha. The heavy treatment was a variation of the conventional treatment with a more intense removal designed to promote uneven-aged conversion. It removed a greater volume of wood from the adjacent rows than the conventional treatment, resulting in a lower residual basal area of about $9m^2$/ha. The heavy treatment included the removal of many co-dominant trees and the intent was to recruit a new cohort of seedlings into the stand. Residual trees were dominant and co-dominant trees selected based on tree form and spacing.

The third treatment tested in this study was referred as the staged patch treatment or patch treatment. It consisted of creating clearcut corridors or patches within the stand. The patches were oriented along the contour and were 20 meters wide. Leave strips between the patches were 40 meters wide and were conventionally thinned. The target basal area averaged across the leave strips and patches was 11.5 m^2/ha.

The stand stem distributions by diameter class for each site and their respective pre and post cut basal areas are in Table 3.2. The removal volume was determined from basal area targets for each treatment.

System Productivity

The harvesting system modeled was a crew with 1 feller-buncher, 1 wheeled skidder, 1 knuckleboom loader with a pull-thru delimber, and 3 crew members. The system productivity was estimated using cycle time equations for the skidder and the feller-buncher. Loader productivity was calculated from the gross production information, dividing gross loader productivity (m^3 loaded) per productive machine hours, on a daily basis. Tree size inputs were base on site characteristics and treatment (Tables 3.1 and 3.2).

Skidder Total Cycle Time Equation

Skidding total cycle time was estimated with the equation below:

$CC_{SK} = 171.934 + 0.179*Sk\_dist2 + 0.0116*skntrees$

Where:

CC_{SK} = total skidder cycle time (in seconds);

Sk_dist2 = Total skid distance on a cycle (round trip in meters); and

Skntrees = interaction of Sk_dist2*trees (ntrees = Avg trees/bunch - daily basis).

Average skid distance (total skid distance – roundtrip) was estimated from a distributions of skid distance for the 4, 8, and 12ha stands. Assumptions for generating the distribution included square shaped stands with the deck located in the middle of one side. Skidder productivity was a product of cycles per productive machine hour and volume per cycle. Volume per cycle was estimated using trees and volume per cycle from site data and observed trees per cycle from the production study.

Feller-buncher Total Cycle Time Equations

Feller-buncher total cycle time was estimated with the equation below:

$CC_{FB} = 15.411 + 9.456*Met + 7.6938*ntrees$

Where:

CC_{FB} = total feller-buncher cycle time (in seconds);

ntrees = number of trees/cycle; and

Met = dummy variable for thinning method (met = 1 for selection cut and met = 0 for row cut).

Feller-buncher equation inputs came from site characteristics and production data observations from each site. Feller-buncher cycle times were produced for both row and selection thinning. Productivity was calculated based on the ratio of row to selection thinning which changed for each treatment. The conventional treatment had a 20% row removal followed by a light selection removal. The heavy treatment consisted of a 20% row removal followed by a heavy selection removal. The patch treatment was simulated with 40% row removal and the selection thinning across the remaining 60% of the site.

The number of trees per cycle corresponded to the average number of trees per feller-buncher accumulation for each cycle and was taken from production data. Number of trees per cycle was negatively related to tree size. The system productivity equaled the limiting or lower daily productivity of either the skidder or the feller-buncher for each treatment, site, and area.

Stand Sizes

Size effect was analyzed in relation to the variation in skid distance and the distribution of moving costs. Stands sizes were selected based on the private ownership pattern at the WUI in the Southern US and the range of tract sizes in which loggers usually operate. Sizes of 4, 8, and 12 hectares were selected. According to Birch (1997) over 93% of the private landowners in the Southern US have ownerships within this range.

Cost Analyses

Hourly costs were estimated using an after-tax cash flow method (Tufts et al. 1989). The method was incorporated into a spreadsheet developed by Tufts (unpublished) and used widely in logging business training in Alabama (Smidt, personal communication, Auburn University 2004). The after-tax cash flow approach allows the consideration of the time value of the money, income tax effects, and inflation, as well as the usual operating and investment costs. Cost inputs consist of fixed and operational cost assumptions. Cost assumptions for the machines are in Table 3.3.

Fixed and Operational Costs

Fixed machine costs included depreciation plus interest rate, insurance, and taxes. Purchase prices were taken from Brinker et al. (2002). Interest, discount, and insurance rates were 7%, 4%, and 6%, respectively. The salvage value for the machines was estimated to be 20% of the purchase price. Machine life was expected to be 6 years.

Operational machine costs included fuel, lubricants, maintenance and repairs, and labor and benefits. Maintenance and repair (M&R) include everything from simple repairs to major component replacement and are usually the most unpredictable of all machine costs. For these analyses, M&R cost assumptions from Brinker et al. (2002) were used. Fuel costs were calculated using the fuel consumption rate estimated by Wang and LeDoux (2003), of 15.2 liters/PMH, 13.3 liters/PMH, and 7.6 liters/PMH for the feller-buncher, skidder, and loader, respectively. A liter of fuel was assumed to be US$0.35. Lubricants costs were calculated as a percentage of fuel cost (36.8% of fuel cost) as suggested by Brinker et al. (2002). The labor cost rate of US$12.50/hour was based on the information provided by the loggers involved in this study. Fringe benefits were assumed to be 30% of the base wages (Lanford and Stokes 1996). Scheduled machine hours (SMH) were assumed to be 2000 hours/year (Wang and LeDoux 2003, Klepac and Rummer 2000, Caulfield and Tufts 1989, and Miyata 1980). This amount is equivalent to 223 days per year operating 9 hours per day. The maximum utilization rate (UR) used for cost analysis was 79% and 76% for the feller-buncher and the skidder, respectively.

Moving and Hauling Costs

Moving and hauling costs are also included in logging rate. Moving cost refers to the costs involved in moving the harvesting crew and equipment to the harvest site, and includes direct costs for moving equipment and labor time, and indirect costs of lost equipment operation and operational overhead costs during the move (Cubbage 1983). For this study moving costs was incorporated on a per move basis to the logging rate. Move costs were a flat rate of US$1,500.00/move and covered the expense required to move an average distance of 50 kilometers (Greene et al. 1988). The flat rate was calculated assuming machine moving costs of US$250.00 for the feller-buncher and US$750.00 for the skidder and the loader. The cost of lost production and labor totaled US$500.00 per move.

Hauling costs involved the transportation of the wood from the logging site to the mill. I assumed an average distance to the mill of 80 kilometers and a flat rate of US$100.00 per load for hauling. An average load size of 25.8 m^3 yielded a cost of US$3.88/$m^3$. I assumed that trucking capacity did not limit production.

The logging rates for each of the 27 scenarios that result from 3 treatments, 3 sites and 3 sizes were calculated by adding the harvesting system costs, moving costs, and the hauling costs. Delivered price, or the value paid for the wood at the mill, was assumed to be US\$24.00/ton (US\$24.50/m^3) for pulpwood and US\$31.00/ton (US\$31.70/m^3) for chip and saw (International Woodfiber Report 2004). The conversion from English tons to m^3 was made using the weight and volume formulas for loblolly pine proposed by Newbold et al. (2001).

RESULTS AND DISCUSSION

System Productivity

The system productivity is summarized in Table 3.4. The heavy treatment resulted in the greatest skidder productivity. However, skidder productivity of the heavy and patch treatments were similar. Skidder productivity decreased as stand size increased reflecting the negative effect of skid distance on the machine productivity. The feller-buncher productivity did not vary with stand size. Feller-buncher productivity was greatest for the patch treatment due to the higher productivity of the row removal and the greater percentage of the site volume removed in rows. Also, the larger average volume per tree increased productivity of the medium and large tree sites.

Cost Analyses

The breakdown of logging cost estimates for the small, medium, and large tree sites is shown in Table 3.5. Treatment had an impact on machine costs across all the combinations of size and site. Stand size negatively affected skidder costs since mean skid distance was shortest for the 4ha stand and longest for the 12ha stand. Skidder costs were lower for the heavy and patch treatment at all stand sizes since those treatments increased the volume per cycle. Feller-buncher cost was affected to a small degree by size but only because limits in skidder productivity reduced feller buncher utilization rates. Feller buncher costs were equivalent for the patch and the heavy treatments, but for the conventional treatment costs were higher. Patch treatment affected feller-buncher costs because it altered the proportion of row thinning which had higher productivity. Increases in average tree size also lowered feller-buncher costs.

Moving costs were calculated on a per move basis, and were negatively related to total volume removed. Overall the heaviest removal (volume/ha) was made on the heavy treatment at the medium tree site (Table 3.6).

In all the 27 scenarios the skidder was the limiting factor and had the highest cost per unit (US$/m^3). The highest system cost was for the 4ha/conventional/small tree site scenario due to both the high moving costs and the lowest volume per tree. The lowest costs were at the 8ha/heavy medium/large tree site scenarios. However, the 12ha stands had costs similar to the 8ha stands. Even though the volumes removed on the 12ha stands were higher, the costs were affected by higher skidding costs. The medium tree site resulted in lower or similar costs per unit than the large tree site since the higher density resulted in greater volume removed, which reduced moving costs (see Table 3.6).

Table 3.7 compares the logging rates to residual values (US$/m^3) of the three stand sizes. For all stand sizes the conventional treatment had the highest costs and lowest residual values. At the smallest stand size, the medium tree site had the highest residual value due the difference in volume removed (Figure 3.1). In the 8 and the 12ha stand sizes the residual values for large and medium sites were similar for the conventional treatment, but the effect of greater average value of wood (chip and saw) in the large site generated larger residual values per cubic meter for the heavy and patch treatments (Figures 3.2 and 3.3). However, in a total revenue per stand perspective, the larger volume removed on the medium tree stands resulted in the largest residual values among the three sites (see Table 3.6).

Figure 3.4 presents a comparison between logging costs and residual values for the conventional treatment as a function of site differences and stand size. The 8 and the 12ha stands had similar values reflecting the impact of high skidding costs on the 12ha stands versus the reduction per unit in moving costs. A comparison between the 8 and 12ha stands showed little difference in costs or residual values. Also, changes in chip and saw volume removed (medium vs. large) did not compensate for the increased costs per cubic meter involved in harvesting the 12ha stands.

Overall, the greatest gain in residual value (about US\$3.10/m^3) was observed by comparing the conventional to the heavy treatment in the 4ha stand (Figure 3.5). The result was maintained for 8 ha stand (Figure 3.6) and 12ha (Figure 3.7). The differences between the heavy and patch treatments were small by comparison in spite of the differences in feller-buncher productivity. The greater volume removed compensated for lower productivity for the heavy treatment.

CONCLUSIONS

Productivity was affected by site differences and overall was higher for the large tree site (site with the largest trees), followed by the medium and low tree sites. Stand size negatively affected skidder productivity, reflecting the negative effect of skid distance on the machine productivity. The skidder was always the limiting factor on the productivity of the systems. The feller-buncher productivity was mainly affected by thinning method and tree size. Since felling was not a limiting factor changes in productivity only affected the variable costs per unit. Distribution of fixed machine costs per unit volume was set by the limiting factor, usually skidding.

Treatment affected harvesting costs. Within the stand size range of 4-12ha the conventional treatment had the highest costs and lowest residual values per unit (US$/m^3). The heavy treatment had the highest residual value due to the greatest removal rate and highest productivity. Heavy removals at 4ha stands make a big difference adding up to US$3.10/m^3 to the residual value. That may add enough incentive for wood buyers and loggers to attempt these harvests. Stand sizes differences were important because of the fixed costs involved (Cubbage 1982 and Wilhoit and Rummer 1999). Moving costs per unit were higher for the smallest stand but changed little between the two larger stands. The small site had the highest logging costs rates and lowest residual values among the sites. At chip and saw volumes with the modeled range (3-19%) the added value of chip and saw does not equal the effect of higher volumes.

Landowners with smallest stands (4ha) could benefit from either alternative treatment. Under the assumptions here, alternative treatments can increase residual value, but it may not be enough to make these sites more attractive to buyers, than they are with a conventional treatment. Analysis showed that there is little added value (residual value - US$/m^3) for landowners that have 8ha versus 12ha stands, but landowners should be cautious since move in costs can be highly variable. Difficult to access stands could easily increase moving cost ($\$/m^3$).

From a cost perspective the heavy and the patch treatments may make harvesting small acreages more attractive to buyers. Since only 1st thinning opportunities were addressed, we did not see much affect from product value. In reality product value is the driving factor in attractiveness of small volume sales (Kittredge 1996) and landowners may be able to achieve gains by delaying thinning to produce more chip and saw, especially if prices differences increase. Owners of small tracts will always be at a disadvantage in marketing timber and they will likely have to market stands extremely well and take advantage of treatment opportunities whenever they occur (Kittredge 1996). If the alternative treatments described here satisfy management objectives they could play a role in marketing these stands.

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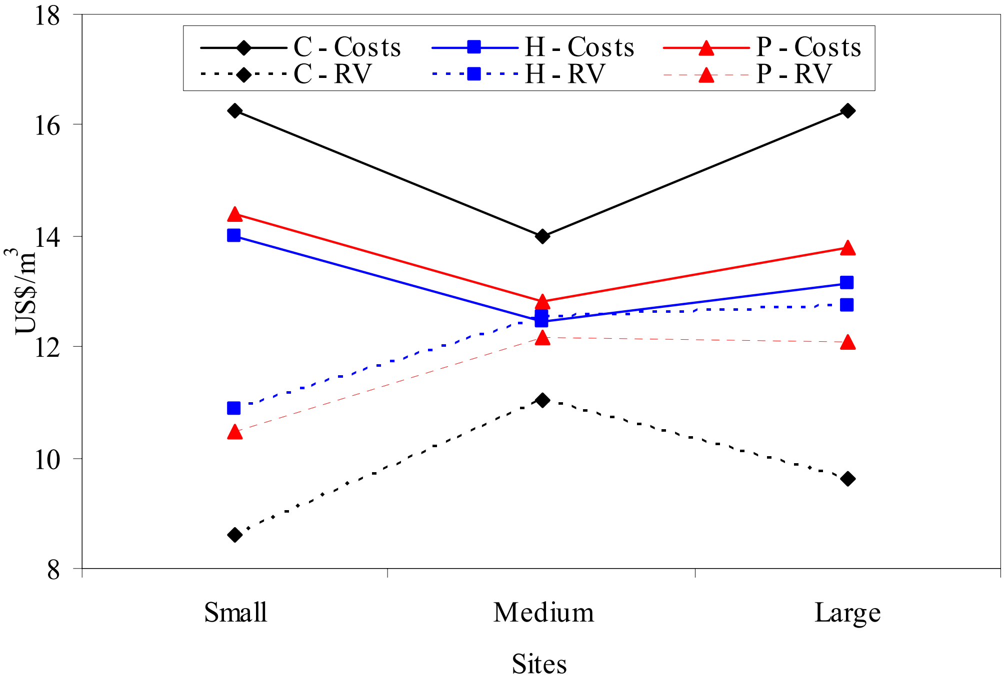

Figure 3.1. **Logging costs (Costs) and residual values (RV) for the 4ha stand size, for the Conventional (C); Heavy (H); and Patch (P) treatments.**

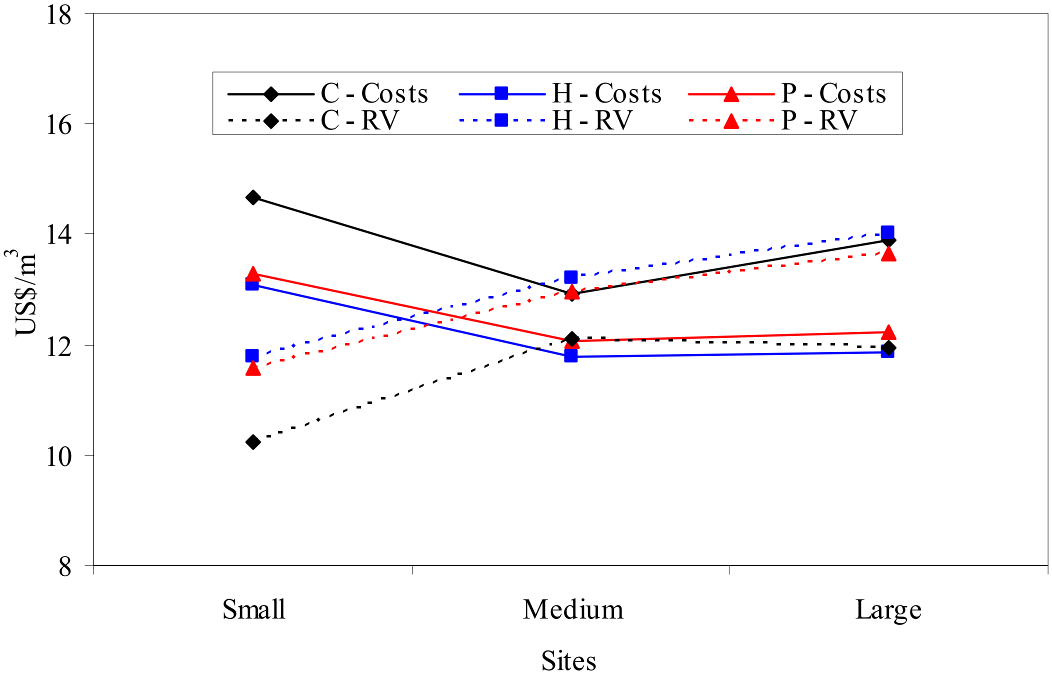

Figure 3.2. **Logging costs (Costs) and residual values (RV) for the 8ha stand size, for the Conventional (C); Heavy (H); and Patch (P) treatments.**

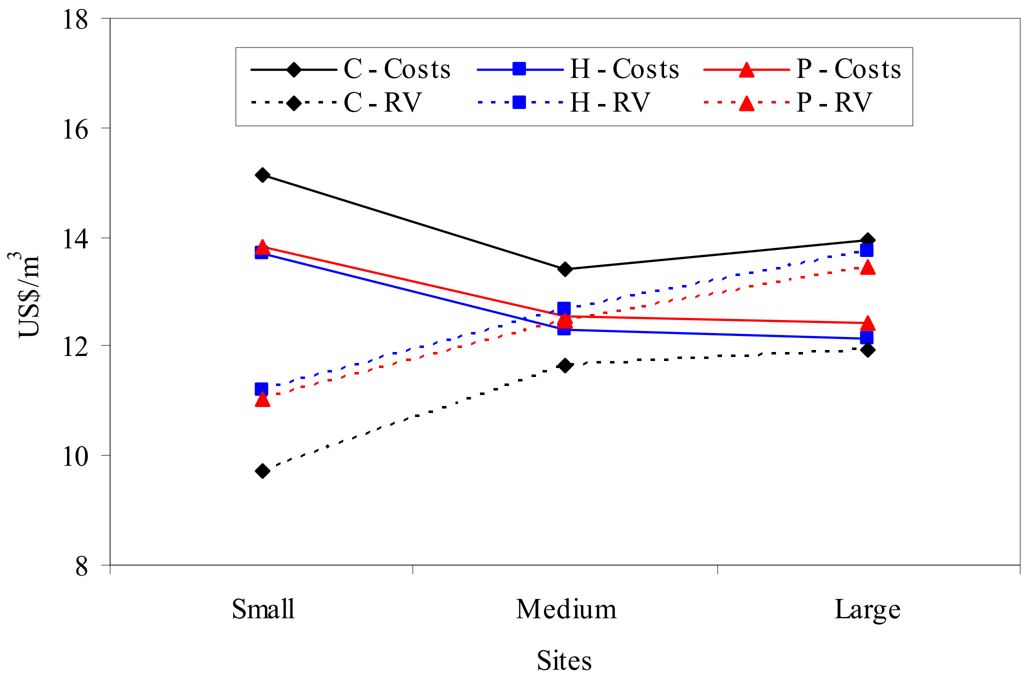

Figure 3.3. Logging costs (Costs) and residual values (RV) for the 12ha stand size, for the Conventional (C); Heavy (H); and Patch (P) treatments.

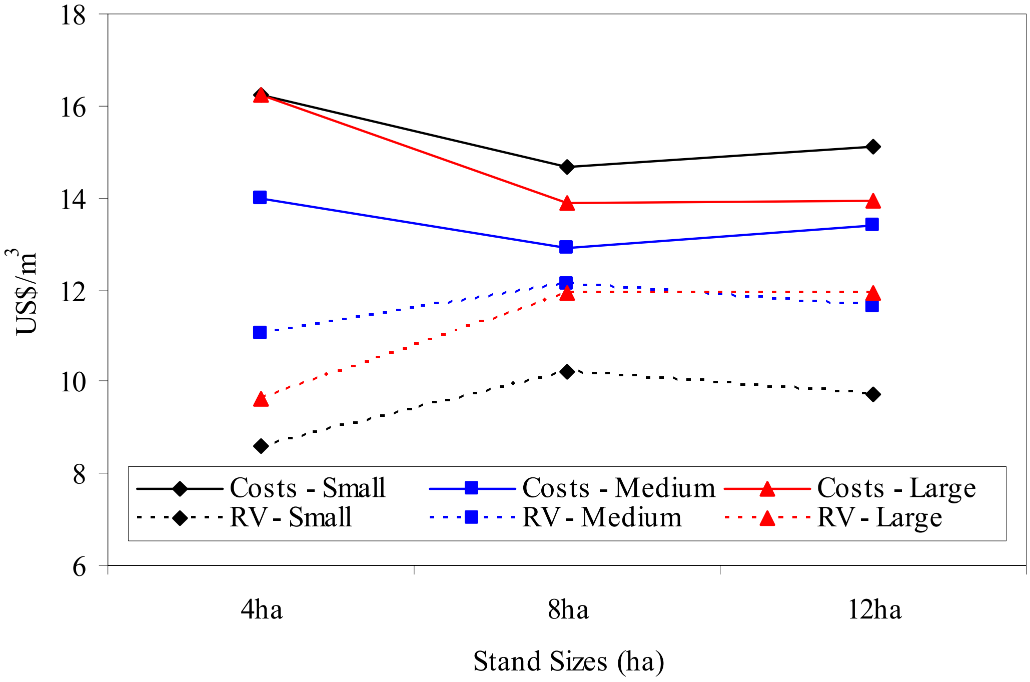

Figure 3.4. **Logging costs (Costs) and residual values (RV) across stand size for small, medium, and large sites.**

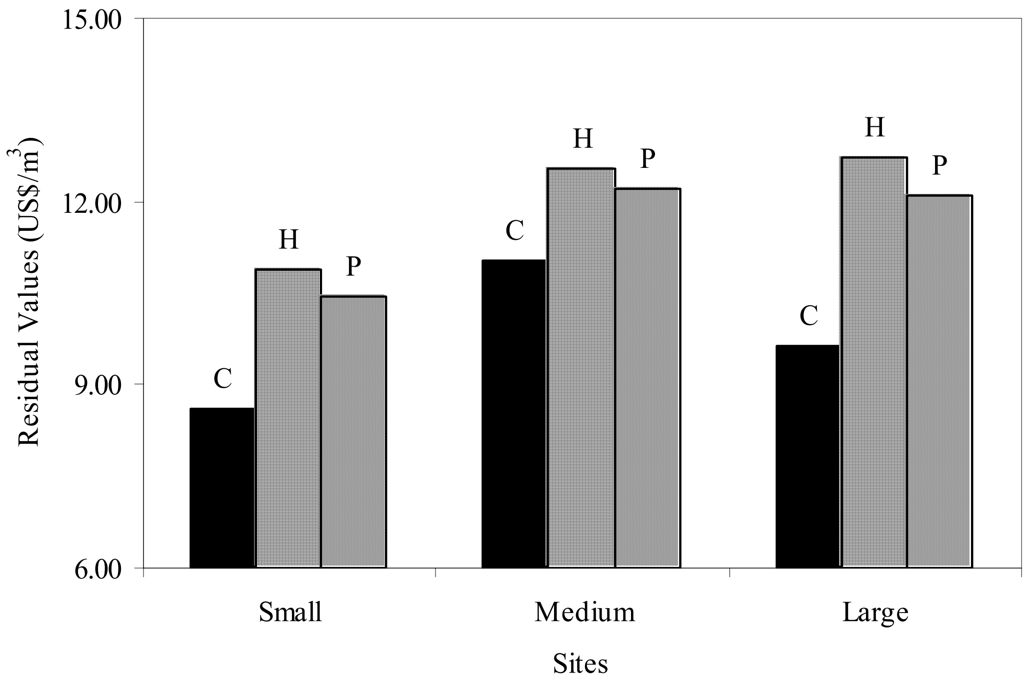

Figure 3.5. **Residual value comparison for Conventional (C); Heavy (H); and Patch (P) treatments within small, medium, and large sites for the 4ha stand size.**

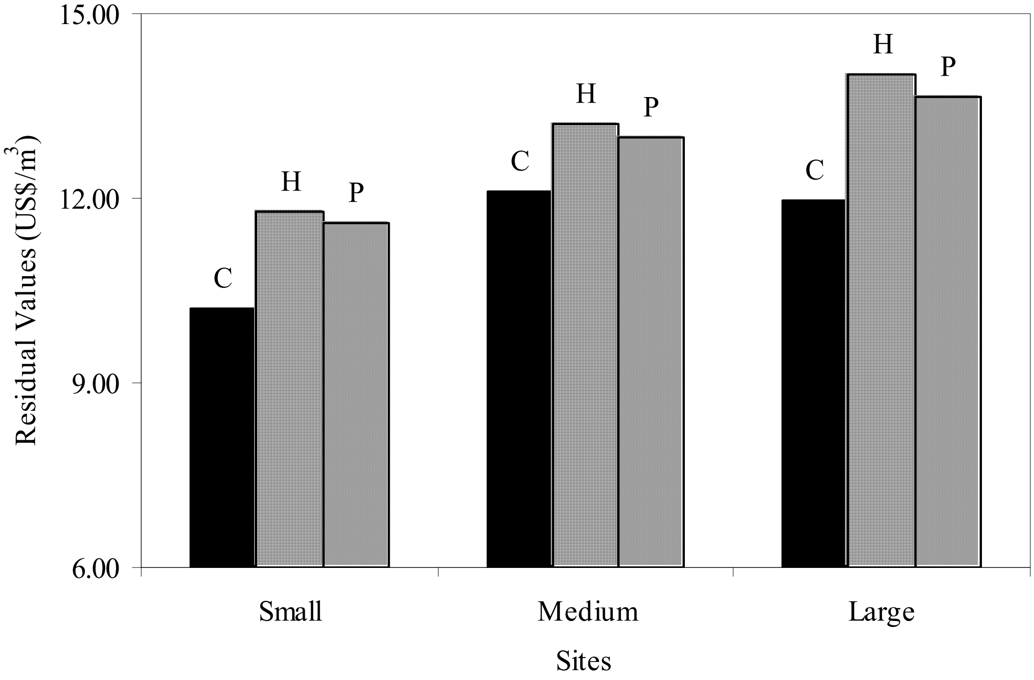

Figure 3.6. **Residual value comparison for Conventional (C); Heavy (H); and Patch (P) treatments within small, medium, and large sites for the 8ha stand size.**

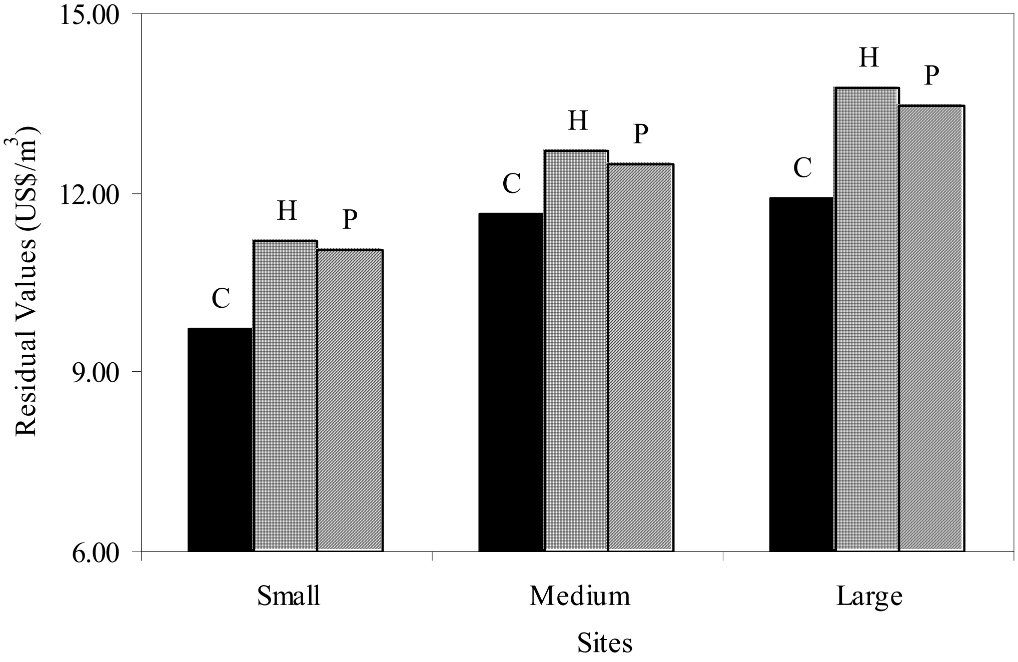

Figure 3.7. **Residual value comparison for Conventional (C); Heavy (H); and Patch (P) treatments within small, medium, and large sites for the 12ha stand size.**

Table 3.1. **Sites characteristics for small, medium, and large tree sites.**

Site	Age (years)	Site Index Base 25 (m)	Product Class (%)		Trees /ha	Basal Area (m^2/ha) Pre cut	Tree Volume (m^3)
			Chip and saw	Pulpwood			
Small	14	19.8	3	97	1849	32	0.072
Medium	14	21.3	7	93	1679	34	0.106
Large	18	18.3	19	81	1205	30	0.110

Table 3.2. **Stand tables and removal assumptions for Conventional (Conv), Heavy, and Patch treatments and small, medium, and large tree sites.**

			Trees cut (%)[1]			**Trees remaining (#/ha)**			**Basal area (BA) remaining (m^2/ha)**		
Small											
DBH (cm)	Trees/ ha	BA (m^2/ha)	Conv	Heavy	Patch	Conv	Heavy	Patch	Conv	Heavy	Patch
10	738	5.9	100	100	100	0	0	0	0.0	0.0	0.0
15	718	12.9	50	100	66	362	0	241	6.5	0.0	4.3
20	361	11.5	28	32	46	260	245	195	8.3	7.9	6.2
25	32	1.6	28	28	46	23	23	17	1.2	1.2	0.9
Total	**1849**	**32.0**				**645**	**268**	**453**	**16.0**	**9.0**	**11.5**
Medium											
10	430	3.4	100	100	100	0	0	0	0.0	0.0	0.0
15	726	13.1	74	100	84	192	0	113	3.4	0.0	2.0
20	483	15.5	28	46	46	348	262	261	11.1	8.4	8.3
25	40	2.0	28	28	46	29	29	22	1.5	1.5	1.1
Total	**1679**	**34.0**				**568**	**291**	**396**	**16.0**	**9.0**	**11.5**
Large											
10	259	2.1	100	100	100	0	0	0	0.0	0.0	0.0
15	357	6.4	92	100	100	29	0	0	0.5	0.0	0.0
20	468	15.0	28	71	47	337	135	250	10.8	4.3	8.0
25	109	5.6	28	28	46	78	78	59	4.0	4.0	3.0
30	7	0.5	28	28	46	5	5	4	0.4	0.4	0.3
35	5	0.5	28	28	46	3	3	2	0.3	0.3	0.2
Total	**1205**	**30.0**				**452**	**222**	**315**	**16.0**	**9.0**	**11.5**

[1] **Trees cut % = % trees removed from each DBH class**

Table 3.3. Assumptions for machine costs calculations.

	Skidder	Feller-buncher	Loader
Purchase Price (US$)	172,530.00	184,100.00	120,601.00
Economic Life (years)	6	6	6
Scheduled Machine Hours (SMH/year)	2000	2000	2000
Days per year	223	223	223
Fuel and Lube Cost (US$/PMH)	6.36	7.27	3.64
Maintenace and Repairs (US$/PMH)	20.70	22.36	13.36
Labor Rate (US$/hour)	12.50	12.50	12.50
Fringe Benefit (%)	30.00	30.00	30.00
Insurance (%)	6.00	6.00	6.00
Discount Rate (%)	4.00	4.00	4.00
Finance APR (%)	7.00	7.00	7.00
Marginal Tax Rate (%)	25.00	25.00	25.00
Salvage Value (%)	20.00	20.00	20.00
Inflate Fuel and Lube (%)	0.00	0.00	0.00
Inflate Maintenance and Repairs (%)	10.00	0.00	10.00
Inflate Labor (%)	0.00	0.00	0.00

Table 3.4. **Machine productivity results for treatment per site (Small; Medium; and Large), and stand size (4; 8; and 12ha). Site data for three treatments (Conventional; Heavy; and Patch). The feller-buncher productivity is estimated for both row and selection components, and the average based on treatment attributes.**

					Skidder (m^3/PMH)				
		Conventional			**Heavy**			**Patch**	
	4ha	**8ha**	**12ha**	**4ha**	**8ha**	**12ha**	**4ha**	**8ha**	**12ha**
Small	20.99	18.36	15.46	23.35	20.42	17.20	23.72	20.75	17.47
Medium	23.41	20.73	17.70	25.91	22.94	19.58	25.41	22.50	19.21
Large	23.83	21.12	18.05	27.60	24.47	20.91	27.20	24.11	20.60
					Feller-buncher (m^3/PMH)				
Small									
Selection	23.57	23.57	23.57	26.23	26.23	26.23	26.64	26.64	26.64
Row	27.49	27.49	27.49	30.59	30.59	30.59	31.07	31.07	31.07
Average	**25.53**	**25.53**	**25.53**	**27.68**	**27.68**	**27.68**	**29.59**	**29.59**	**29.59**
Medium									
Selection	32.13	32.13	32.13	35.56	35.56	35.56	34.88	34.88	34.88
Row	37.07	37.07	37.07	41.02	41.02	41.02	40.23	40.23	40.23
Average	**34.60**	**34.60**	**34.60**	**37.38**	**37.38**	**37.38**	**38.45**	**38.45**	**38.45**
Large									
Selection	41.54	41.54	41.54	48.11	48.11	48.11	47.41	47.41	47.41
Row	49.75	49.75	49.75	57.63	57.63	57.63	56.79	56.79	56.79
Average	**45.65**	**45.65**	**46.65**	**51.28**	**51.28**	**51.28**	**53.66**	**53.66**	**53.66**

Table 3.5. Estimated logging costs for each combination of site, treatment, and stand size.

Small site (US\$/m^3)									
	Conventional			**Heavy**			**Patch**		
	4ha	**8ha**	**12ha**	**4ha**	**8ha**	**12ha**	**4ha**	**8ha**	**12ha**
Skidder	2.84	3.25	3.86	2.56	2.92	3.47	2.52	2.88	3.42
Feller-buncher	2.65	2.91	3.29	2.38	2.61	2.96	2.47	2.70	3.03
Loader	1.94	2.14	2.45	1.79	1.98	2.26	1.77	1.95	2.23
System	7.43	8.30	9.61	6.73	7.51	8.68	6.76	7.53	8.68
Hauling	3.88	3.88	3.88	3.88	3.88	3.88	3.88	3.88	3.88
Moving	4.94	2.47	1.65	3.39	1.69	1.13	3.77	1.89	1.26
Total	16.26	14.65	15.13	14.00	13.09	13.69	14.41	13.29	13.82
Delivered price	24.87	24.87	24.87	24.88	24.88	24.88	24.87	24.87	24.87
Residual values	8.61	10.22	9.74	10.88	11.79	11.19	10.46	11.58	11.05
Medium site (US\$/m^3)									
Skidder	2.55	2.88	3.37	2.30	2.60	3.05	2.35	2.65	3.11
Feller-buncher	2.24	2.45	2.76	2.02	2.21	2.49	2.06	2.25	2.54
Loader	1.79	1.96	2.21	1.66	1.81	2.04	1.69	1.84	2.07
System	6.58	7.28	8.33	5.99	6.63	7.58	6.10	6.75	7.72
Hauling	3.88	3.88	3.88	3.88	3.88	3.88	3.88	3.88	3.88
Moving	3.52	1.76	1.17	2.59	1.29	0.86	2.85	1.43	0.95
Total	13.98	12.92	13.39	12.46	11.80	12.32	12.83	12.05	12.55
Delivered price	25.02	25.02	25.02	25.01	25.01	25.01	25.02	25.02	25.02
Residual values	11.04	12.10	11.63	12.55	13.21	12.69	12.19	12.97	12.47
Large site (US\$/m^3)									
Skidder	2.50	2.83	3.31	2.16	2.44	2.85	2.19	2.48	2.90
Feller-buncher	2.06	2.26	2.56	1.78	1.95	2.21	1.80	1.98	2.24
Loader	1.77	1.93	2.17	1.59	1.73	1.94	1.61	1.75	1.96
System	6.33	7.01	8.04	5.53	6.12	7.01	5.60	6.20	7.10
Hauling	3.88	3.88	3.88	3.88	3.88	3.88	3.88	3.88	3.88
Moving	6.03	3.02	2.01	3.73	1.86	1.24	4.30	2.15	1.43
Total	16.24	13.91	13.93	13.14	11.86	12.13	13.79	12.23	12.42
Delivered price	25.86	25.86	25.86	25.87	25.87	25.87	25.87	25.87	25.87
Residual values	9.62	11.95	11.93	12.73	14.01	13.74	12.08	13.64	13.45

Table 3.6 Total volume removed and total residual value for all scenarios. Residual values in US$/ha are in parentheses.

Stand area(ha)	Volume Removed (m^3/stand)			Residual Value (US$/stand)		
	Convention	Heavy	Patch	Conventional	Heavy	Patch
Small site						
4	348	508	456	2996 (749)	5527 (1382)	4770 (1192)
8	696	1016	912	7113 (889)	11979 (1497)	10561 (1320)
12	1044	1524	1368	10169 (847)	17054 (1421)	15116 (1260)
Medium site						
4	488	668	604	5388 (1347)	8383 (2096)	7363 (1841)
8	976	1336	1208	11810 (1476)	17648 (2206)	15668 (1958)
12	1464	2004	1812	17026 (1419)	25431 (2119)	22596 (1883)
Large site						
4	288	464	400	2770 (693)	5545 (1386)	4832 (1208)
8	576	928	800	6883 (860)	13001 (1625)	10912 (1364)
12	864	1392	1200	10307 (859)	19126 (1594)	16140 (1345)

Table 3.7. Logging cost (US$/m^3) and residual value (RV = US$/m^3) for all scenarios.

	4 ha stand		8 ha stand		12 ha stand	
Treatment	**$/m^3**	**RV $/m^3**	**$/m^3**	**RV $/m^3**	**$/m^3**	**RV $/m^3**
Small site						
Conventional	16.26	8.61	14.65	10.22	15.13	9.74
Heavy	14.00	10.88	13.09	11.79	13.69	11.19
Patch	14.41	10.46	13.29	11.58	13.82	11.05
Medium site						
Conventional	13.98	11.04	12.92	12.10	13.39	11.63
Heavy	12.46	12.55	11.80	13.21	12.32	12.69
Patch	12.83	12.19	12.05	12.97	12.55	12.47
Large site						
Conventional	16.24	9.62	13.91	11.95	13.93	11.93
Heavy	13.14	12.73	11.86	14.01	12.13	13.74
Patch	13.79	12.08	12.23	13.64	12.42	13.45

IV. SUMMARY

We tested in this study alternative treatments for harvesting of small loblolly pine plantations at the Wildland Urban Interface (WUI) using fully mechanized commercial thinning. Consideration in method selection was given to harvesting productivity, economics, aesthetics, and practical concerns for long term stand management at the WUI.

First we compared the harvesting productivity of conventional thinning practices to a heavy thinning treatment. The heavy treatment intended to convert even-aged stands to uneven-aged stands by conducting a more intense removal and subsequent recruitment of reproduction. There were no treatment differences in productivity for the skidder or the feller-buncher. Skid distance and bunch size significantly affected skidder productivity. Skidder cycle time increased with the increase of these variables. Feller-buncher productivity was affected by the number of trees per cycle and thinning method. Larger accumulations caused longer cycles and selection thinning resulted in longer cycle times than the row thinning. The heavy treatment increased loader utilization.

The second part of this study simulated a third thinning treatment, the patch treatment. I compared harvesting productivity and costs of the three thinning treatments in different stands and for different stand sizes (4, 8, and 12 hectares). Skidder productivity limited system productivity on all combinations. Productivity of the skidder was affected by skidding (stand size) and tree size (site differences). Feller-buncher productivity was affected mainly by thinning method and treatments with greater row thinning had higher productivity. Harvesting costs were affected by treatment, site differences, and stand size. Overall, the heavy and the patch treatments resulted in similar costs and residual values. Treatment differences were greatest in the smallest stand size (4ha) where the difference in volume removed resulted in a gain of up to US\$3.10/m^3 to the residual value. Stand size differences were important due to the fixed costs associated with move in and set up activities. Moving costs change little from the 8 to the 12ha stands. Site differences influenced residual values as a function of tree size (chip and saw or pulpwood products) and total volume removed per hectare. The greatest removal occurred on the heavy thinning at the medium site.

In summary, the results of this study suggest that there is a potential for landowners to benefit from alternative mechanical treatments. Alternative treatments resulted in considerable gains in residual value, especially for the smallest stands. The additional income may make harvesting more available to landowners and attractive to buyers. From the aesthetic and long term management perspectives, these treatments may be suitable to land managers at the WUI. The continuous tree cover aspect of the heavy and patch treatments may result in less visual impact. The decision to use a treatment depends primarily on the landowner objectives. If the alternative treatments proposed here satisfy the objectives they could play an important role in marketing small stands.

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