A POST-HARVEST EVALUATION OF MECHANIZED THINNING IN NATURAL LOBLOLLY PINE IN THE COASTAL PLAIN OF ARKANSAS

by

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ABSTRACT

A POST-HARVEST EVALUATION OF MECHANIZED THINNING IN NATURAL LOBLOLLY PINE IN THE COASTAL PLAIN OF ARKANSAS

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Commercial thinning in the South is a highly efficient mechanized operation which operates year round. Southern winters are typically wet; therefore, the potential for soil rutting and compaction exists when heavy machines are used. This study was undertaken to determine if mechanized thinning in wet weather impacted the soils and affected tree growth.

Soil and tree growth data were collected from two natural loblolly pine stands located in the coastal plain of Arkansas that were thinned 4-5 years previously. The Demonstration Area was 1.9 acres in size and 26 years old, with a site index of 50 feet (base age 25). The second study area, the Deer Camp Area, was 4.0 acres in size and 31 years old, with a site index of 60 feet (base age 25). The soil physical conditions in both study areas were not significantly impacted by the mechanized thinning operation. In general, the soils had bulk densities below 1.3 Mg/m^3, approximately 15% macropore space, 30% micropore space, and ruts were generally less than 6 inches deep.

Trees growing greater than 12 feet from the skidding corridors were compared with trees growing 0-12 feet from the skidding corridors. In both study areas, radial growth of the trees next to the corridors exceeded that of those between corridors after thinning. Other results varied by site. On the Demonstration Area the trees in the 0-

12 foot zone had larger DBHs and crown widths than the trees between corridors; but the trees growing more than 12 feet from the corridor were taller than the trees growing within 12 feet of the corridor. In the Deer Camp Area, the trees within 12 feet of the corridor had larger DBHs, total heights, and heights to the live crown than the trees growing more than 12 feet from the corridor. The main reason tree growth next to the corridors exceeded that of trees between corridors (>12 feet from corridor) was because of heavier thinning in the areas closer to the corridor.

The only post-thinning growth reductions were found in trees growing near the deepest ruts (i.e. >6 inches deep). In both study areas, these trees had extremely poor radial growth responses after the mechanized thinning, increasing only 1.6% in the Demonstration Area and decreasing 4.7% in the Deer Camp Area. The trees located on ruts less than 6 inches deep had the highest radial growth responses to the thinning operation. The trees on 3-6 inch ruts responded 20.2% in the Demonstration Area and 28.6% in the Deer Camp Area; on 0-3 inch deep ruts, the trees responded 15.0% and 23.3%, respectively.

Bole damage was also found to reduce the growth of residual loblolly pine. Damaged trees growing within 6 feet of the rut had the lowest increase in radial growth after thinning. On both study areas, the damaged trees located more than 6 feet from the rut did not seem to be adversely affected by the bole damage. Overall, mature loblolly pine seems tolerant of small amounts of soil disturbance and basal damage, but, if both occur, then tree growth is severely reduced.

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CHAPTER 1

INTRODUCTION

PROBLEM STATEMENT

In the southern United States, much of the forest resource consists of pine stands originating from abandoned agricultural land or plantations planted with improved loblolly pine (*Pinus taeda*) seedlings. In 1985, 61.9 million acres in the South were classified as pine forests, of which 41 million acres were in natural pine stands (Brown and McWilliams 1990). Adams and Haynes (1991) estimated that in 1990, 13.7 million acres of southern pine acreage (natural and plantation) ranged from 13-22 years of age. This age group is generally considered optimal for the first commercial thinning because maximum biological growth is achieved by thinning early and tree size is large enough for economical harvesting (Robe 1988).

Thinning reduces the number of stems per unit area of land and elevates individual stem growth of loblolly pine above natural levels over longer time periods. Intermediate thinning also recovers biomass traditionally lost to competition, mortality, and reduces competition stress for space, light, nutrients, and water, allowing the residual trees to increase growth (Smith 1986). Finally, thinning is a method of keeping the trees healthy and vigorous so the stand does not fall prey to disease and insects. Improper thinning or failure to thin can make loblolly pine susceptible to Southern Pine Beetle (SPB) attack (Nebeker and Hodges 1985). Doggett (1985) states, "research indicates that the less dense stands resulting from thinning should have fewer SPB problems, and, when problems occur, their impact will be less than in dense stands." However, *Fomes Annosus* can be a problem in parts of the south because of root damage after thinning (Pierrot 1984).

Three major methods of thinning are practiced in the south: row, selection, and a combination of row and selection methods. A row thinning removes one complete row of trees and leaves several rows (i.e. 5 rows) unharvested between the harvested rows (Pierrot 1984). Selection thinning involves harvesting individual stems throughout the stand; however, this is an extremely expensive thinning option often resulting in higher levels of residual stand damage (Reisinger 1983). A combination thinning involves harvesting a complete row to create access corridors through out the stand and then removing individual trees (typically based on crown classification) from between the corridors (Reisinger 1983).

The majority of commercial thinning operations today utilize mechanized equipment (i.e. feller-buncher and grapple skidders). These mechanized systems typically operate year-round, regardless of the weather, to supply wood consuming mills with fiber. Unfortunately, the ability of the harvesting machines to operate and the ability of the soil to tolerate trafficking decreases as soil moisture increases. Therefore, soil damage (e.g., rutting and compaction) can occur when stands are thinned during the wet winter months. "Rutting" is the term used by loggers and foresters to denote soil disturbances such as compaction and puddling. Inherent with compaction and soil puddling is decreased soil aeration, infiltration, and internal drainage.

Heavy machine traffic during harvesting can alter the physical properties of forest soils by reducing macroporosity (i.e. pores >0.06 millimeters in diameter which cannot hold water against the force of gravity) and increasing soil bulk density (soil mass per volume of soil). Soil strength is the ability of a soil to resist penetration, which correlates to the load bearing capacity of the soil. As soil moisture increases, soil strength decreases, thus soil damage resulting from heavy equipment travel may increase (Greacen and Sands 1980). Soil trafficking and associated changes in soil physical properties, such as soil bulk density, hydraulic conductivity (i.e. distance water moves through the soil per unit of time), and soil strength, can occur on more than fifty percent of the site (Gent et al. 1983). The majority of soil disturbance is concentrated in skidding corridors when mechanized harvesting equipment is used because the machinery traffic is intensified in these areas.

Changes in soil physical properties can adversely affect tree growth and site productivity. Several researchers have tried to quantify the changes in soil physical properties and determine their effects on tree growth and future site quality. Firth and Murphy (1989) and Perry (1964) reported reductions in tree height growth of 26.8% and 12.9%, respectively, on compacted soils in old wagon trails. Others have documented reduced seedling growth on compacted soils (Reisinger et al. 1988; Lockaby and Vidrine 1984). Only a few studies have dealt with the impacts of mechanized thinning on tree growth. Total area impacted and the severity of damage by mechanized thinning operations were documented by Murphy (1982), but the study did not include data on growth reductions resulting from soil damage. King and Haines (1979) found no detrimental impacts after mechanically thinning loblolly pine on soils with less than 13% moisture content.

A pilot study in two natural loblolly pine stands in Arkansas indicated that height growth of trees located next to skidding corridors may have been reduced after mechanized thinning operations (Reisinger et al. 1991). The main concern of this pilot study was the effect of significant rutting (i.e. ruts deeper than 6 inches) on tree growth after thinning. This study was limited in scope because of a lack of pre-thinning data and limitations of the study design; therefore, a more detailed study was recommended to determine the impact of machine traffic on tree growth.

OBJECTIVES

Thinning is an accepted and widely used silvicultural operation, but little information has been gathered about the possible detrimental effects of heavy equipment travel through the residual stand. Most of the research that has been published centers on measurements taken within one year after thinning; however, information on the long-term responses of loblolly pine to soil disturbance is also critical. To clarify the responses of loblolly pine several years after thinning, this project was implemented to determine the effects, if any, of heavy machine traffic on the growth of residual crop trees. The research involved detailed analysis of soil physical properties, tree growth, and stand damage in two stands in southwestern Arkansas where compaction and rutting of skidding corridors occurred during a wet weather thinning operation.

The specific research objectives were:

(1) To document the changes in soil physical properties (i.e. bulk density, saturated hydraulic conductivity, and soil porosity) 4-5 years after a mechanized thinning operation.

(2) To determine if changes in soil physical properties affected growth of trees located adjacent to skidding corridors compared to trees growing between the corridors 4-5 years after mechanized thinning.

(3) To determine if residual stand damage caused during the operation affected tree growth 4-5 years after mechanized thinning.

CHAPTER 2

LITERATURE REVIEW

INTRODUCTION

Thinning operations in both pine plantations and natural pine stands remains a controversial topic among forest land managers. Much of the controversy centers on the economics of harvesting small stems, the best silvicultural method, the best equipment to use, residual stand damage, and the difficulty of attaining legal highway loads (Reisinger 1983; Greene et al. 1987). Also thinning is often difficult to coordinate because thinning requirements are based on silvicultural aspects, but loggers must adapt to these silvicultural requirements based on equipment ability and economics (Greene et al. 1987). As a result, a wealth of literature exists from the past 20-30 years dealing with the advantages and disadvantages of various silvicultural prescriptions and the economics of thinning. This chapter will concentrate on literature pertaining to mechanized harvesting systems employed for thinning, the types of soil disturbance that can occur, and the potential effects on residual tree growth.

THINNING SYSTEMS AND OPERATING METHODS

Thinning systems have undergone rapid technological change to keep up with the increased demand for thinning. Long gone is the crew consisting of two men, a chainsaw and a short-wood truck (Corwin et al. 1988). Most contractors presently involved in thinning in the South have the same equipment as a typical sawlog logging operation: a feller-buncher, grapple skidder, knuckle-boom loader, and tree-length trailers. Some contractors also have down-sized their equipment for added maneuverability and lower operating costs. Few contractors have bought dedicated equipment, since thinning typically is not as profitable as a final harvest. Corwin et al. (1988) identified the following three major types of mechanized systems used in the South to thin pine stands:

1. Motor-manual/forwarder
2. Feller-buncher/grapple skidder combination
3. In-woods chipper

The majority (i.e. 87%) of thinning operations currently employ the familiar feller-buncher and grapple skidder equipment spread, but more recent thinning operations utilize small three wheeled or tracked feller-bunchers. Lanford and Stokes (1982) believe that smaller equipment minimizes residual stand damage and reduces harvesting costs. Watson et al. (1986) modeled the optimum size of a feller-buncher for thinning pine plantations and found the machine should be 7 feet wide and 20 feet long, with a 40 degree angle of articulation. Similarly, Schroering et al. (1986) found that the Franklin 105 feller-buncher was too large and unmaneuverable to perform selective thinnings unless corridor access passages were created.

Accompanying the feller-buncher in most thinnings is a rubber-tired grapple skidder. Greene and Stokes (1988) tested a Franklin Model 105 grapple skidder, considered a small skidder (77 horsepower), and found that the machine allowed the contractor to move wood at competitive prices. A study by Robe (1988) disagreed, finding that larger skidders (e.g., Franklin Model 170, 185 horsepower) were able to move wood more cost effectively than small skidders. Robe (1988) also found that the larger skidder actually left skid trails less compacted (estimated by soil strength data) than the skid-trails trafficked by the smaller machine. These conflicting studies suggest that an ideal equipment spread is a matter of debate. Robe (1988) summarizes the situation by saying "determining optimal skidder size for thinning would involve finding the balance between productivity and residual stand damage."

Other studies have examined alternate thinning systems such as a feller-buncher and forwarders instead of skidders. Greene et al. (1987) found that forwarding product lengths was always more expensive than tree length logging. Likewise, single-grip harvesters have also been tried in several areas of the south. Greene et al. (1984) found that a Valmet 940 single grip harvester slightly improved productivity but the cost per productive man hour was 12% more expensive than manual bucking and limbing. Greene et al. (1987) also found that thinning operations using single grip harvesters utilized capital less efficiently and the cost per unit of wood was more expensive than manual operations (i.e. chainsaw limbing). These systems have merit in terms of production and reduced residual stand damage, but fail to provide a cost-effective method of harvesting pine pulpwood.

The most common method of thinning in the South is the corridor thinning method (Corwin et al. 1988, Robe 1988, Greene and Stokes 1988, Schroering et al. 1986). This operating method clears corridors through the stand at set intervals (e.g., every third or fifth row in plantations or every 40 feet in natural stands) that serve as transportation thoroughfares through the stand. The feller-buncher operator then selectively removes trees between the corridors and places them in the corridors for later transport to the log deck. Because the rubber-tired grapple skidder is the machine of choice for moving wood from the stand to the deck, soil disturbance (e.g., ruts, compaction, and exposed mineral soil) is generally concentrated in the access corridors.

TYPES OF SOIL DISTURBANCE

Soil compaction and puddling after harvesting are potentially detrimental to the future productivity of a forested site (Froehlich 1973; Greacen and Sands 1980; Froehlich 1982; Reisinger et al. 1988). Research indicates that both seedling growth and residual tree growth can be adversely affected by soil disturbance. However, most of the literature deals only with poor regeneration on compacted skid trails and landing areas. It stands to reason that semi-mature loblolly pine would be similarly affected by intermediate harvesting practices such as mechanical thinning.

The condition of a site and its soils after harvesting can vary widely depending on several factors, including soil types, moisture and extent of traffic during harvesting. Soil disturbance may be categorized as slight, moderate or severe.

Slightly disturbed soils, typically occur after light vehicle traffic on dry soils, do not have visible ruts or exposed mineral soil. Miller and Sirois (1986) define slightly disturbed soils as soils that have the litter removed or mineral soil and litter are mixed. Slightly disturbed soils can recover in short time periods, and such disturbances do not have statistically significant impacts on future site quality (Lockaby and Vidrine 1984). Most areas classified as slightly disturbed include feller-buncher tracks or secondary skid trails that were only lightly trafficked.

Moderately disturbed soils have more visible compaction, exposed mineral soil and/or compacted shallow ruts (Firth 1989). These soils do not recover as quickly as slightly disturbed soils and compaction may inhibit future tree growth. Moderately disturbed soils are typically found on secondary or primary skid trails that are utilized more frequently.

Severely disturbed soils are those with extremely deep ruts, puddled soil, and complete mineral soil exposure (Greacen and Sands 1980). Also, typically the subsoil is exposed (Miller and Sirois 1986). Maximum soil compaction and soil puddling occur when soil moisture is at or above field capacity. Severely damaged soils are often encountered on primary skid trails, incorrect stream or slough crossings, log decks, and haul roads. Severe soil damage requires longer recovery periods and may have detrimental effects on future site quality (Perry 1964; Reisinger et al. 1988).

Although it is not known exactly how long severely damaged soils need to recover, the time is long enough to affect the next crop of trees significantly or possibly to negate beneficial effects of a thinning operation. Recovery times after disturbance will vary according to soil type, moisture content, extent of disturbance, and the distribution and amount of organic matter (Reisinger et al. 1988). Estimates of recovery times vary between researchers, but all concede that severely disturbed soils require more than twelve years to return to pre-harvest states (Perry 1964; Hatchell et al. 1970; Dickerson 1976). Froehlich (1979), studying the effects of soil compaction on young Ponderosa pine growing in the Ochoco National Forest (Oregon), measured compaction after logging and found that the newly compacted soils had "... essentially the same (bulk) densities at each depth as did the sixteen year old ruts." Perry (1964) estimated that severely disturbed Cecil soils of old wagon trails or log roads in central North Carolina could require 40 years to recover. Hatchell et al. (1970), however, stated that severely disturbed loamy sand and fine sandy loam soils in Virginia and South Carolina would need only 18 years to recover. In Mississippi, severely disturbed soils with textures ranging from loamy sand to silty clay loam needed 12 years to recover, according to Dickerson (1976). However, Moehring and Rawls (1970) found that severe disturbance on only one or two sides did not decrease loblolly pine growth. When these trees were trafficked on 3 or 4 sides, basal area was significantly lower than the basal areas of the undisturbed trees.

Soil Compaction

Soil compaction is an increase in bulk density, or the soil mass per unit volume. Soil structure changes as compaction occurs: soil strength can increase at low soil moisture contents and total porosity is reduced. The reduction in porosity occurs when the macropores and large voids are filled with soil particles (Greacen and Sands 1980). Compaction also increases the relative percentage of water held at field capacity but reduces the air content, water infiltration rate, and saturated hydraulic conductivity of the soil (Greacen and Sands 1980; Murphy 1983; Dickerson 1976).

In forested stands, research has shown that the majority of soil compaction occurs during the first several passes of machinery over an area (Lockaby and Vidrine 1984). Hatchell et al. (1970) found that two skidding passes produced bulk densities only 10% lower than bulk densities measured after nine skidding passes. However, Murphy (1982) found that as the number of loaded passes increased, the severity of soil damage also increased. Compaction is a function of both static weight and shear forces generated by forestry machinery (Greacen and Sands 1980). The shear forces generated by drive tire torque and steering forces can double the static load of a given piece of machinery (Greacen and Sands 1980). Raghaven et al. (1977) and Davies et al. (1973) found that wheelslip, a shear force, of agricultural tractors caused significant compaction. Davies et al. (1973) state, "Wheelslip proved to be more important in causing compaction than additional wheel loading, and this effect was more pronounced for more powerful tractors."

As the moisture content of the soil increases above field capacity, the potential for soil damage is much greater (Wingate-Hill and Jakobsen 1982). Soils become increasingly sensitive to damage as moisture content increases because the water acts as a lubricant between the soil particles, allowing them to move from their natural positions more easily (Greacen and Sands 1980). On wet loblolly pine sites decreasing amounts of air-filled pore space causes a reduction in soil strength (Hatchell et al. 1970). The same trends found by Hatchell et al. (1970) have been shown for the sandy soils of South Australia (Greacen and Sands 1980).

Other factors affecting soil strength are organic matter content and soil type. Greacen and Sands (1980) state, "soils rich in organic matter are ... more difficult to compact." Wingate-Hill and Jakobsen (1982) also report that soil organic matter increases the soil's compressive strength. The clay, sand, and silt content of a soil also determines its susceptibility to compaction (Froehlich 1974). As the amount of clay increases in a soil, the potential for soil compaction increases. Sand, however, decreases a soil's susceptibility to compaction.

The amount of compaction and soil disturbance that occurs during silvicultural operations varies widely and is not well documented. Bulk density was 14% higher in the wheel ruts of primary skid trails than the surrounding undisturbed sandy loams of the Georgia Piedment (Campbell et al. 1973). In Mississippi, bulk density increased an average of 20% in the wheel ruts of the skid trails and log decks compared to bulk densities of untrafficked soil (Dickerson 1976). Karr and Guo (1991) found that bulk density increased as rut depth increased. Aust et al. (1990) found that salvage logging in the coastal plain of South Carolina with rubber-tired skidders (e.g. 28" wide tires and 68" wide tires) on a saturated sandy loam increased bulk density by 23% on compacted 28" tire skid trails, and 9% on 68" tire skid trails compared to undisturbed soil bulk density levels. In Swedish thinning operations, the amount of soil disturbance and compression of the soil has been shown to increase linearly with the volume of timber transported (Fries 1974). However, Snider and Miller (1985) reported no significant increase in bulk density after logging extremely dry volcanic ash soils in eastern Oregon.

As compaction or puddling increases, the availability of nutrients, moisture, and air needed for tree growth decreases (Karr et al. 1987). Murphy (1983) adds that root growth tends to slow after soils are compacted because the tree roots are mechanically impeded, aeration is reduced, and mycorrhizal activity is slowed. Foil and Ralston (1967) found root growth of loblolly pine to be restricted in soils with a bulk density of 1.33 Mg/m^3 or greater. Another study reported that bulk densities greater than 1.40 Mg/m^3 resulted in reduced root mass (Mitchell et al. 1982). Reisinger et al. (1988) state, "roots must exert a force greater than the cohesive forces binding the soil particles if the roots are to penetrate pores of smaller diameters than themselves." Such small diameter pores can be formed by compaction of the soil by heavy machinery, thus hindering the root growth of many tree species.

Soil Puddling

As soils become saturated with water, machine traffic destroys the soil's shear strength, causing deep ruts to form. As the machines negotiate these deep ruts, the churning tires mix the soil horizons. Puddling begins with shear failure of the soil after machine operation on poorly drained soils (Greacen and Sands 1980). After the disturbance, the clay particles in the soil align so that they are parallel (Shoulders and Terry 1978), and inhibit water and air movement into the soil upon soil drying (Sharma and DeDatta 1985). Bodman and Rubin (1948) state that for any given pressure on the soil, the higher the moisture content, the more complete is the relative destruction of the soil pore space, resulting in puddled soils. The soil structure is destroyed when soils are puddled, dramatically increasing bulk density. Increased bulk density results in decreased infiltration and decreased hydraulic conductivity, even after the soil has dried (Reisinger et al. 1988). Because infiltration is reduced, puddled soils are saturated for longer time periods than unpuddled soils and deform more easily than unpuddled soils after trafficking (Shoulders and Terry 1978).

EFFECTS OF SOIL DISTURBANCE ON SEEDLING GROWTH

A substantial amount of research has gone into determining if machine-caused soil disturbance (e.g., compaction and rutting) reduces tree growth and site productivity. In New Zealand, *Pinus radiata* was found to have poorer form and growth rates on compacted soils than on uncompacted soils (Murphy 1983; Firth and Murphy 1989). Murphy (1983) found *P. radiata* height growth to be significantly less for seedlings growing on previously compacted skid trails. Four year old trees growing on compacted skid trails were 2.05 meters tall, compared to 3.02 meter heights for trees grown off the skid trails. Two years later, the trees growing on uncompacted soils were 1.5 meters taller than the trees growing in the skid trails, and at age 7.5, the height difference was 1.4 meters (Firth and Murphy 1989). Also, because of increased machine traffic on the landing areas, *P. radiata* growing closer to the landing had poorer growth rates than their counterparts on less traveled skid trails (Firth and Murphy 1989). Trees growing adjacent to the skid trails did not experience detrimental growth impacts up to age 7.5, but trees growing on skid trails had malformations (i.e. butt sweep and toppling) 18% more often than trees growing on uncompacted soils (Firth and Murphy 1989).

Compaction has also been found to affect other tree species. A 14% growth reduction has been recorded for western hemlock on compacted soils (Froehlich 1979). In the foothills of Alberta, Canada, Corns (1988) planted lodgepole pine and white spruce seeds on four soil types, each having different compaction rates, to assess the effect of bulk density on tree growth. The largest decrease in diameter occurred on a clay loam: lodgepole pine seedlings on undisturbed soils (1.2 Mg/m^3) had diameters of 2.06 mm, but at a bulk density of 1.35 Mg/m^3 diameter was reduced to 1.61 mm (Corns 1988). Therefore, a 0.15 Mg/m^3 increase in soil strength reduced lodgepole pine seedling diameter growth by 25.5% during a fifteen week period. In the same soil, white spruce diameter growth decreased only 7.5% when the bulk density increased from 1.2 Mg/m^3 to 1.35 Mg/m^3 (Corns 1988). For Douglas fir, Wert and Thomas (1981) determined that 11.8% of total volume was lost because of reduced growth on skid trails and decks. This translates into an extra four years of growth for trees on skid trails to reach breast height compared to trees growing in uncompacted soils.

In the South, several studies have also examined the effects of soil disturbance on seedling growth. Loblolly pine seedlings were found to have severely reduced height growth (48%) on compacted primary skid trails of the lower coastal plain of South Carolina (Hatchell et al. 1970). Lockaby and Vidrine (1984) found a 39 to 59% reduction in height growth of five year old loblolly pine on compacted soils. Mitchell et al. (1982) and Simmons and Ezell (1982) found that root systems of loblolly pine on compacted soils were significantly smaller than those of loblolly pine growing in noncompacted areas of the stand.

Foil and Ralston (1967) also found that 30 day old seedling survival rates were reduced from 92% on uncompacted soils to only 46% on greenhouse soils puddled and compacted to 1.3 Mg/m^3. They also found that the relationship between root length and root weight was negative and linear when regressed by soil compaction, resulting in severe root growth restrictions at bulk densities above 1.33 Mg/m^3. Foil and Ralston (1967) note the problem of "separating the effects of mechanical impedance, poor aeration, and unfavorable moisture relation on plant growth." Hatchell et al. (1970) conclude, "The data do not lead to a full understanding of the reasons why soil compaction reduced growth, and it is probable that soil strength and other physical properties were influential, but the soil aeration appears to be a dominant factor." Although the soil property that affects growth most is not known, changes in soil physical properties after harvesting can impose deleterious effects on the continued growth of forest trees.

EFFECTS OF SOIL DISTURBANCE ON THINNED STANDS

Fewer research studies have been completed on the influence of machine traffic on residual trees left after a partial, selective harvest or a commercial thinning. An Oregon thinning study conducted in Douglas fir found that soil damage severity increased as the number of loaded machine passes over an area increased (Murphy 1982). Murphy (1982) also found that a FMC 100 tracked skidder caused one fifth less damage on dry soils than on wet soils. Previously, Froehlich (1979) found that moderately impacted trees showed a 6% reduction in growth after thinning, and heavily impacted trees lost 12% of their growth potential over a 16 year period. Perry (1964) found that 26-year old plantation loblolly pine growing on old roads left after clearcutting had a 55% reduction in volume growth when compared to trees growing adjacent to the log road. The average diameter of the trees in the ruts was 2.4 inches smaller than comparable trees in undisturbed soil (Perry 1964). Trees that were not in the ruts were also 8 feet taller than those growing in the road. For 40 year old loblolly pine growing in Arkansas, a 43% diameter growth reduction on compacted silt loam soils was found after wet-weather intermediate harvesting with large crawler tractors (Moehring and Rawls 1970).

Nebeker and Hodges (1985) reported that the amount and duration of decreased growth after thinning depends on many factors, such as the intensity of site and stand disturbances (e.g., soil compaction, root breakage and bole wounding). They also found that as the distance from the skid trail decreased and depth of the rut increased, volume growth decreased by more than 60% (Figure 2.1).

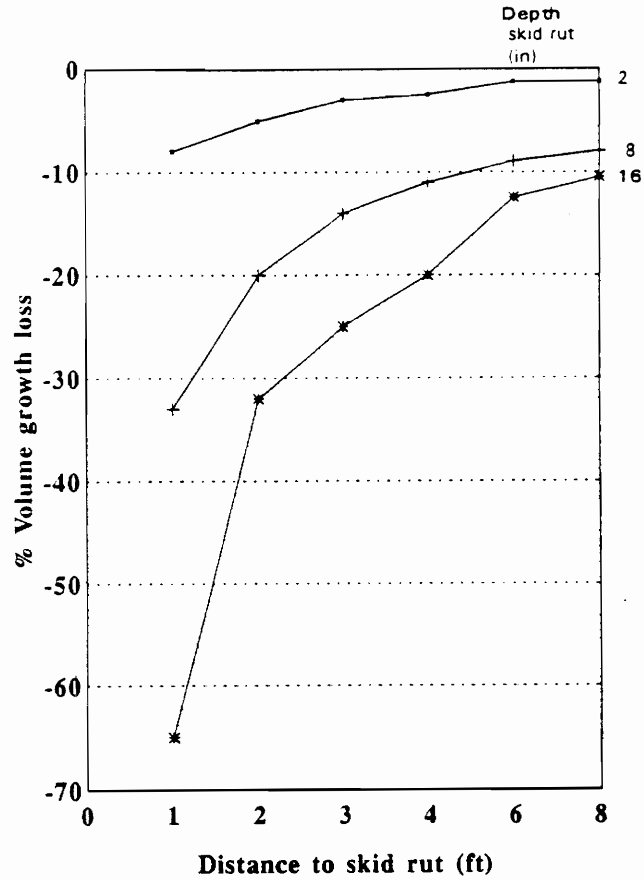

Figure 2.1. Percent growth reductions for thinned loblolly pine by distance to skid rut and depth of rut. (From Nebeker and Hodges 1985)

A pilot study in the coastal plain of Arkansas found a 3.8% reduction in height growth of natural loblolly pine trees growing adjacent to compacted skid trails after mechanized thinning 4 years earlier (Reisinger et al. 1991). Tree diameters were also smaller but were not statistically significant (alpha=0.10) (Reisinger et al. 1991). However, this study was limited in scope and was based on a small sample size of 59 paired trees.

Several studies contradict the findings of the aforementioned studies. King and Haines (1979) and King (1979) found that on soils with 13% moisture content (less than field capacity), no soil damage occurred during thinning. Moehring and Rawls (1970) also reported that neither tree growth nor soil physical properties were significantly affected by logging on dry soils. Nickolich (1983) found that one year after thinning, rutting did not affect tree growth of loblolly pine on a somewhat poorly drained silty clay loam soil in Mississippi. She also found a "slight, positive relationship between soil rutting and growth of residual trees ..." one year after thinning on a well-drained fine sandy loam. Nickolich (1983) noted that one year is not long enough to determine the long-term impacts of soil disturbance on residual loblolly pine growth. Nebeker and Hodges (1983), based on the work of Nickolich (1983), found mixed results in loblolly pine growth one year after thinning. They report that the trees in the study did respond to the thinning, but they believe that the growth response may have eclipsed any negative effects of soil damage caused by thinning.

Mechanical damage to residual trees after thinning can also reduce growth and open infection courts for many species of fungi and insects (Nebeker and Hodges 1985). Belanger et al. (1979) states that, "treatments that are not cautiously applied may create conditions conducive to pest colonization or alter environmental factors that may offset any benefits from thinning." Exact growth reductions caused by mechanical stand damage after thinning have not been quantified in the south (Nebeker and Hodges 1985). However, Froehlich (1976) believes such thinning damage is responsible for losses exceeding 10% in other forest regions.

CHAPTER 3

METHODS AND PROCEDURES

Soil disturbance has been correlated with reduced seedling growth and with reduced residual tree growth after mechanized thinning in the south and in other forest regions. However, research documenting the effects of machine traffic on loblolly pine growth after intermediate thinnings has been limited to measuring tree growth only one year after thinning. One growing season probably is not enough time to define the interactions between the residual trees and the site. Therefore, this study was undertaken to evaluate the effects of soil disturbance on stands that were thinned at least four years earlier. This chapter details the methods and procedures used in the study.

The methods and procedures were designed to determine if the mechanized thinning operation affected the growth of trees located adjacent to skidding corridors compared to trees growing between the corridors. Since the two stands in the study were of natural origin and no pre-harvest data were available, increment cores were used to determine if the growth rates of remaining trees were significantly different before and after thinning. If no pre-thin biologic growth differences were found between trees in these stands, any differences in growth rates after thinning may be partially explained by changes in soil physical properties.

STUDY SITES

The study was conducted in two natural loblolly pine stands in Grant County, Arkansas on land owned by International Paper Company. The terrain varied from rolling to flat coastal plain sites, and both sites were thinned during the winter months when soil moisture was high. Skidding corridors in the two study areas contained obvious ruts from the mechanized thinning operations four and five years earlier. Small differences in stand age and site index existed as well as slight differences in topography even though these areas were less than 2 miles apart.

Demonstration Area

The Demonstration Area, is a 26 year old natural loblolly pine stand with a site index of 50 feet (base age 25). The study area was a 1.9 acre portion of a larger thinned area with evenly spaced skidding corridors. As Figure 3.1 illustrates, there were five heavily trafficked skid trails in the study area with very little evidence of cross trafficking. The stand was thinned during the winter of 1988 by a logging contractor using a John Deere JD 70 tracked feller-buncher and a John Deere 750 series grapple skidder. The contractor cleared access corridors into the stand and thinned trees (operator-selected) between the skidding corridors. The trees in this area had some past ice damage and were moderately infested with fusiform rust (*Cronartium fusiforme*). No published soil series data exists for this section of Grant County, Arkansas. However, based on observation, the soil on this site was a moderately drained, crumbly, sandy loam approximately six inches deep on top of an argillic B horizon.

Deer Camp Area

The Deer Camp Area is a 31 year old natural loblolly pine stand with a site index of 60 feet (base age 25). The study area was 4.0 acres in size and thinned in 1987 by the same logging contractor, using the same equipment, as in the Demonstration Area. Access corridors were cleared and operator-selected trees were removed between the corridors. Much of the area was traversed with heavy equipment and the main skid trails ended in a maze of lightly traveled corridors towards the northern study area boundary. Figure 3.2 illustrates the deck location and irregularly spaced primary skidding corridors throughout the stand. The trees within the stand were healthy and did not show symptoms of any fusiform rust. No published soil series data were available for the Deer Camp Area, but the soils on this site were similar to those on the Demonstration Area. The structure was crumbly and the topsoil was approximately four inches deep over an argillic clay layer.

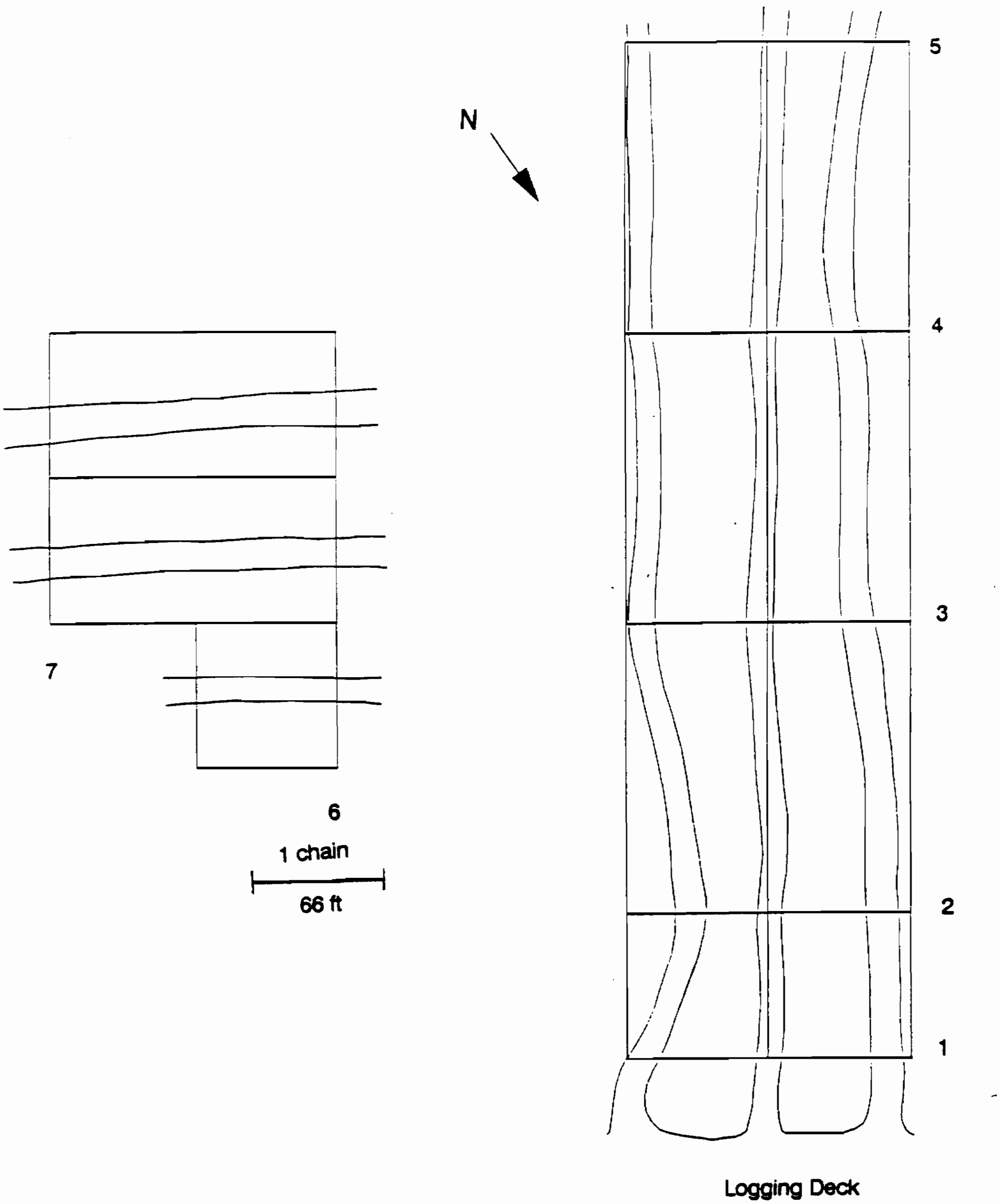

Figure 3.1. Map of Demonstration Area (1.9 acres) showing skid trails, location of landing area, and transect lines.

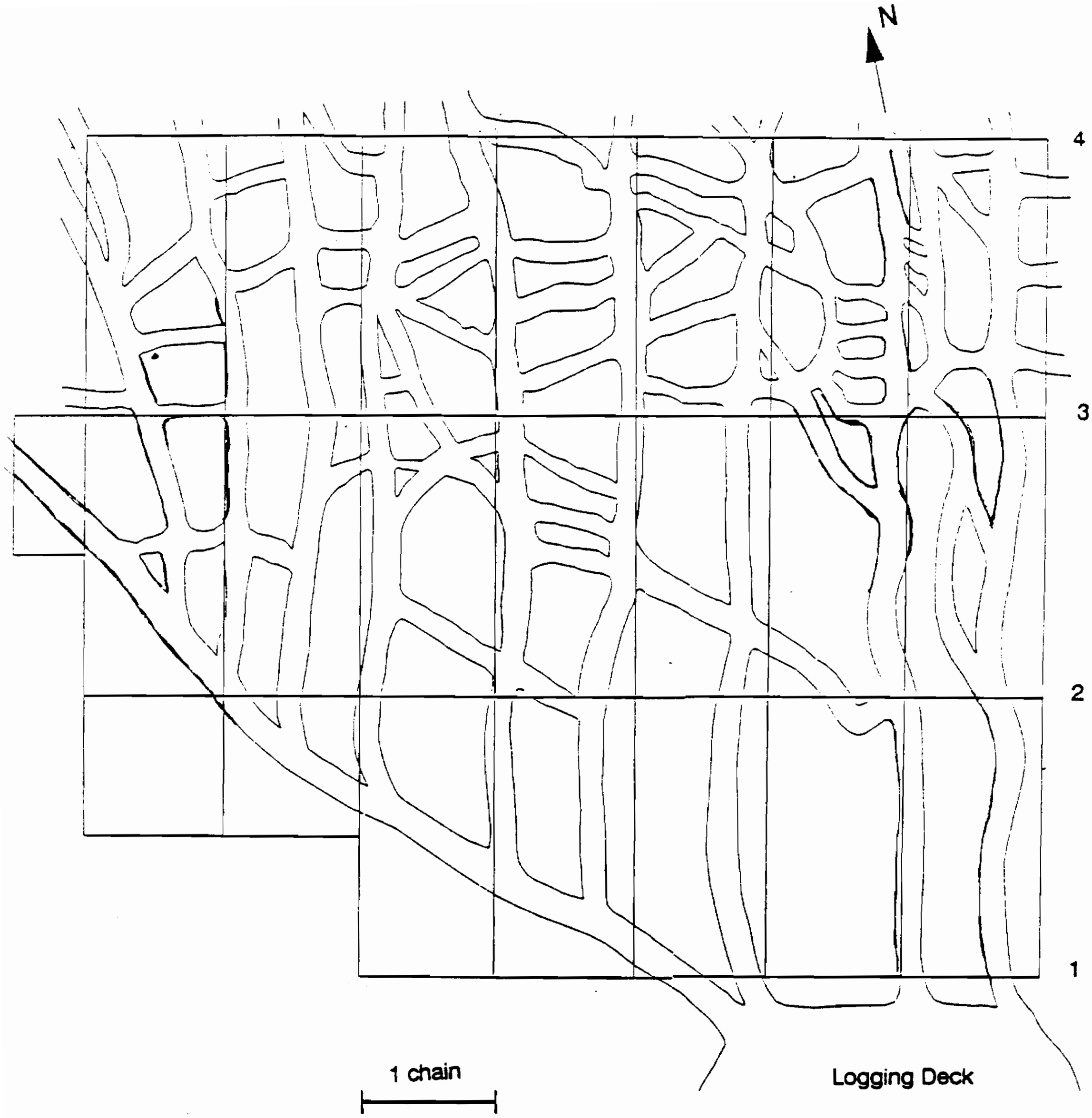

Figure 3.2. Map of Deer Camp Area (4.0 acres) showing skid trails, location of landing area, and transect lines.

SAMPLING METHODS AND DATA COLLECTION

The Demonstration and Deer Camp study boundaries were arranged to encompass the areas with the most severe rutting. East-west transect lines were established 2 chains apart, except where stand boundaries forced the lines to be one chain apart. To ensure grid uniformity, these transect lines were located using a staff compass and steel two chain tape, from a north-south line emanating from the center of the log deck. The transect lines crossed from stand boundary to stand boundary on a N 50 W bearing in the Deer Camp Area. The transect lines in the Demonstration Area were on a N 14 E bearing but did not span from one stand boundary to the other.

Plot centers were established at one chain intervals along each transect line, forming 2x1 chain blocks (132 x 66 ft) as shown in Figures 3.1 and 3.2. Within each block, all trees were consecutively numbered and tagged, by moving north to south through the blocks in 15 foot swathes. Maps were produced to show the location of skid trails and residual trees in each study area.

Two types of data were collected in the field: tree data and soil data. The separation of these two types of data were necessary to document the separate processes occurring in the stand and relate them to tree growth. General information obtained from company records was used to document the time of thinning, soil moisture conditions, and harvesting equipment used during the thinning operation.

Tree Data Collection

Data collected from trees larger than 5 inches in diameter included DBH (inches), height to the base of live crown (feet), total height (feet), crown width (feet), and crown classification. On trees less than 5 inches in diameter and hardwoods, the DBH was recorded so that thinning efficiency could be evaluated. Trees that were mechanically damaged (i.e. bark removed from bole or exposed roots) during thinning were noted so that they could be evaluated separately from undamaged trees.

Basic Tree Measurements

Two perpendicular diameter measurements were taken on each tree with calipers and the results averaged to obtain DBH to the nearest 0.1 inch. Total height and crown height were measured to the nearest foot using a clinometer. Crown width was estimated using a logger's tape. Increment cores were collected from every intermediate, co-dominant and dominant tree within both study areas.

Growth Ring Measurement

From each increment core, a periodic increment (millimeters) was measured for every five years growth before thinning; in addition, average radius (millimeters) and average ring width (millimeters) were measured for the pre-thin period. Post-thin measurements included individual ring widths (millimeters) and periodical annual increment (PAI) (millimeters/year). Also, age, total radial growth from the pith to the bark (millimeters) and mean annual increment (MAI) (millimeters/year) were calculated from the increment cores.

Analysis of the increment cores was used to determine growth rates of individual trees before and after thinning. It was assumed that DBH, height, and age would not sufficiently document specific tree growth patterns because they do not provide information on how each tree grew over time. For example, a tree (not located on a skidding corridor) may have been co-dominant before thinning; after thinning, its growth may have increased, equaling the size of a neighboring tree that was dominant before thinning. The larger tree may have been located next to a major skidding corridor and the soil damage resulting from thinning decreased its annual growth increment. These growth differences would be masked if the only data collected were DBH and total height. Increment core analysis allowed documentation of tree growth patterns before thinning, thereby allowing inferences to be made on post-thinning growth.

The growth rings were measured from a radial line that originated at the pith and ended at the bark. The width of each periodic growth increment on the increment core was measured on the average radius line with Mitoyo 500 digital calipers.

The periodic annual increment (P.A.I.), mean annual increment (M.A.I.) and average diameter of the trees were calculated using the following equations (Smith 1986):

$$\text{P.A.I.} = \frac{\text{width of n rings (mm)}}{\text{n}}$$

where: n = number of growth rings (years)

$$\text{M.A.I.} = \frac{\text{width of radial line (mm)}}{\text{age of tree (yr)}}$$

Merchantable Tree Volume

The merchantable volume of each dominant, co-dominant, and intermediate tree was calculated from a region-specific integral equation obtained from the U.S. Forest Service Experiment Station in Monticello, Arkansas. Farrar and Murphy (1988) describe their volume equation as a taper function fitted to natural loblolly pine in the West Gulf region. The equation uses diameter at breast height and the total height of the tree to determine volume in cubic feet of wood.

$$d = D(H-h)+b_1(H-h)(h-4.5)/H^2+b_2D(H-h)(h-4.5)/H^2+b_3D^2(H-h)(h-4.5)/H^2+b_4(H-h)\quad(h-4.5)(2H-h-4.5)/H^3 \quad \text{if: } 4.5 \leq h \leq H$$

d = predicted stem diameter (in) (o.b.) at height (ft) (h)
h = height above groundline (ft)
D = diameter at breast height (in)
H = total tree height (ft)

Actual cubic foot volumes were obtained from the integrated taper function:

$$V = K_o \int_{hi}^{hu} d^2\, dh$$

K_o = pi/576
d = predicted diameter at height (h)
hu = upper tree height (ft)
hi = lower tree height (ft)

Soil Data Collection

Soil samples taken in the skidding corridors were compared to the samples taken in the untrafficked areas to assess thinning impacts on soil physical properties. Soil bulk density measurements provided information on the level of compaction throughout the study areas. As soil bulk density increases, the macroporosity of the soil decreases, slowing water infiltration and movement through the soil (Greacen and Sands 1980). A reduction in soil drainage, caused by soil compaction, may decrease soil aeration over longer time periods and reduce tree growth. To fully document the soil/plant interaction, it was necessary to determine the porosity percentages of untrafficked soils and soils trafficked by mechanized thinning equipment and to determine how these changes affected the saturated hydraulic conductivity of the soils in study areas. Other data collected included the depth/severity of rutting and a visual assessment classification (severe or slight) of soil disturbance/damage throughout the study areas.

A transect line plot sampling method was used to collect bulk density data from both the Demonstration and Deer Camp Areas. Bulk density core samples were taken every one chain (66 ft.) along each transect line. A bulk density core sampler with a cylinder volume of 96.6 cubic centimeters was used to sample the upper two inches of soil. More detailed soil measurements were taken when the transect lines crossed a skidding corridor. At each corridor crossing, three bulk density cores were taken along a line perpendicular to the corridor at the points shown in Figure 3.3.

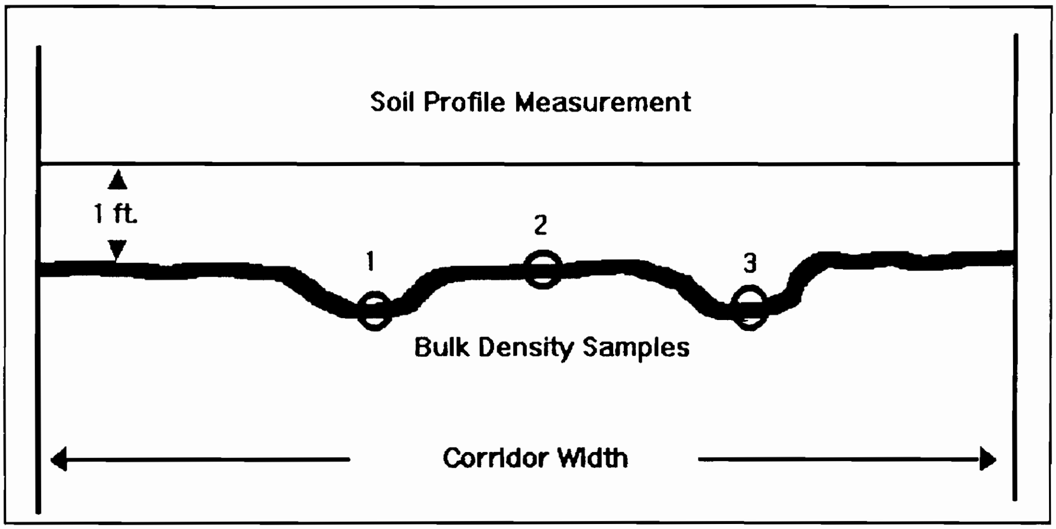

Figure 3.3. Soil sample positions (bulk density) and soil profile measurements within the skidding corridors.

To document the depth/severity of soil disturbance within the corridor, a soil profile was taken where the transect line intersected a corridor. The soil profile was measured by leveling a string approximately one foot above the corridor's surface (Figure 3.3). From this string, the distance to the ground was measured every one-half foot across the corridor. Such measurements provided a micro-topography map detailing the depth and width of any ruts occurring in the skidding corridors.

Laboratory Methods

The following tests were performed on the soil bulk density cores which were collected in the field. The series of tests began with the saturated hydraulic conductivity tests and ended after the soil cores were oven dried to determine soil bulk density.

Saturated Soil Hydraulic Conductivity

The soil cores collected in the field were saturated for at least 48 hours before the saturated hydraulic conductivity measurement was begun. Saturated hydraulic conductivity was determined using the constant head method (Klute and Dirkson 1986). The amount of water flowing through the core per unit time was measured, using a 25 centimeter water head above the soil core. Saturated hydraulic conductivity was calculated by the following equation:

$$K = (Q/At) \times (L/H)$$

Where:
K = saturated hydraulic conductivity (cm/hr)
Q = volume of water passed through sample (cm^3)
A = cross-sectional area of sampled core (cm^2)
t = time per volume of water passed through sample (hr)
L = length of cylinder (cm)
H = 25 cm water head

Values for individual cores were excluded from analysis if they had saturated hydraulic rates which did not correlate with their macroporosity percentage, because of suspected pipe flow.

Soil Porosity

After the saturated hydraulic conductivities of the soil cores were determined, the total porosity, macroporosity, and microporosity percentages were determined using the tension table method (Danielson and Sutherland 1986). The soil cores were again saturated and placed on a tension table (using a 50 centimeter water pressure head). Water was allowed to drain from the macropores for 24 hours and the cores were then weighed. After the bulk density was determined, the total, microporosity (i.e. pores <0.06 mm in diameter which can hold water against pressures up to 15 bars) and macroporosity were determined.

$$\text{Macroporosity (\%)} = \frac{\text{Sat. wt. - FC wt.}}{\text{Cylinder Volume}}$$

$$\text{Microporosity (\%)} = \frac{\text{FC wt. - OD wt.}}{\text{Cylinder volume}}$$

Sat. wt. = weight of saturated soil core.

FC wt. = equilibrium weight [weight of soil when only the capillary pores (i.e. micropores) are filled with water].

OD wt. = oven dry weight (weight of cores after all water removed by baking at 105 degrees Centigrade for 24 hours).

$$\text{Total Porosity (\%)} = \text{Macroporosity} + \text{Microporosity}$$

Soil Bulk Density

After the saturated hydraulic conductivity and porosity tests, the cores were oven dried at 105 degrees Celsius for 24 hours and weighed. Bulk density was calculated by the following equation (Blake and Hartge 1986):

$$\text{Bulk Density} = \frac{\text{Oven dry weight}}{\text{Cylinder volume}}$$

STATISTICAL ANALYSIS

Data analysis for each study area consisted of analyzing tree data and soil data separately as unpaired data. The data were analyzed under the assumption that the variances were unknown and unequal; therefore, the Welch two-sample t-test approximation was used (Ott 1988). All statistical analyses were performed using the Number Cruncher Statistical System, version 5.03 (Hintze 1990) on an IBM-compatible personal computer.

Tree Data Analysis

The trees located next to corridors were compared to trees located in untrafficked areas (i.e. between the corridors). The null hypothesis was that tree growth in the trafficked and untrafficked areas was equal before thinning. The alternative hypothesis was that growth was not equal in the two areas before thinning. The post-thinning growth was tested under the hypothesis that the growth of trees in the untrafficked areas would equal tree growth adjacent to trafficked areas. The alternative hypothesis was that trees growing in untrafficked areas would grow faster than trees growing in areas adjacent to skidding corridors.

The standard errors between the undisturbed and disturbed areas were large and possibly hindered parametric statistical analysis because of the natural loblolly pine stands evaluated. In some cases, graphical analysis of the raw data indicated that the populations may not fit a normal distribution; thus, several parametric statistic assumptions were violated. Therefore, non-parametric statistical tests were used to further support the trends shown by the parametric two-sample t-tests. The non-parametric statistical tests included the Kruskal-Wallis test, analogous to a one-way analysis of variance, to determine whether the different samples occurred within the same population (Sprent 1989). The Kolmogorov-Smirnov test (analogous to a two-sample t-test) was then used to determine where the differences between the samples occurred (Sprent 1989).

A total of 549 loblolly pine trees were measured in the Deer Camp Area, and 341 trees were measured in the Demonstration Area (Table 3.1). Because of problems with the increment cores (i.e. missing pith or missing outer portion of increment core), growth data for 53% of the Deer Camp Area trees was not included in the statistical analysis. Only 10% of the cores in the Demonstration Area could not be utilized.

Table 3.1. Sample sizes of the tree data collected in the Demonstration and Deer Camp Areas.

	Demonstration Area	Deer Camp Area
Total Trees	341	549
Percent Usable Cores	90	53
Trees In-between Corridors	121	97
Trees Within 12 Feet of Corridors	187	161

Soil Data Analysis

More soil core samples were taken in the disturbed areas (i.e. corridors) than in undisturbed areas; three cores were taken each time the transect line crossed a skid trail, whereas only one core was taken at 1 chain intervals along the transect lines. The extra samples from the corridors were needed to reduce the variation so that a meaningful comparison could be made between the disturbed soil samples and the undisturbed samples.

Table 3.2. Sample sizes of the soil data collected in the Demonstration and the Deer Camp Areas.

	Demonstration Area	Deer Camp Area
Total Soil Sample	79	126
Samples From in-between Corridors	21	19
Sample From Corridors	58	107

The soil data from the corridors were compared with the data from the untrafficked areas using two-sample T-tests, testing the hypothesis that there was no change in bulk density, microporosity, macroporosity, total porosity, saturated hydraulic conductivity, and soil strength after mechanized thinning.

CHAPTER 4

RESULTS AND DISCUSSION -- SOIL IMPACTS

The soils in both study areas were similar and had a sandy loam A horizon and argillic B horizon; such soils can be compacted or rutted if the soils are trafficked when wet. Company records do not contain specific information about the soil conditions in the stands at the time of thinning, but the sites were harvested during the winter months. This is the wet season for Arkansas, and ruts ranging upto 24 inches deep were found throughout the study areas. Of the two study areas, the Demonstration Area contained a higher percentage of rutted corridors. The results of the laboratory analysis of the soils from both the Demonstration and Deer Camp Areas are discussed in the remainder of this chapter.

DEMONSTRATION AREA

Soil disturbance on the Demonstration Area was limited to the major skid trails. Based on the soil profile data, soil impacts ranged from slight (no visible rutting) to severe (ruts up to two feet deep). During July, when data collection occurred, the soil moisture was less than 15 percent, yet the deepest ruts still contained standing water.

The test results from the soil physical properties (bulk density, macroporosity, microporosity, total porosity, and saturated hydraulic conductivity) were surprising. Bulk density, the parameter usually thought to be most important, was not significantly different on the disturbed areas (skidding corridors) than on the undisturbed soils (areas that did not contain skid trails or obvious machine traffic). The undisturbed soils had a mean bulk density of 1.15 Mg/m^3 and the disturbed soils had a bulk density of 1.14 Mg/m^3 (Table 4.1). The macroporosity, microporosity and total porosity of the disturbed soils were not significantly different from the undisturbed soil porosities at a $p=0.10$ level (Table 4.1). The saturated hydraulic conductivity of the undisturbed soils was higher on average than that of the disturbed soils, and the standard errors of the two data sets were large. The undisturbed sample's saturated hydraulic conductivity averaged 2.87 cm/hour, which was not significantly different ($p=0.10$) from the disturbed sample's average rate of 2.60 cm/hour (Table 4.1). The mean saturated hydraulic conductivity of the disturbed areas was lower than that of the undisturbed areas, but should not adversely affect soil drainage or tree growth.

Table 4.1. Mean values of the soil physical properties for the undisturbed and disturbed areas in the Demonstration Area.

	Undisturbed Areas			Disturbed Areas			Statistics	
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	t-value	p-level
Bulk Density (Mg/m^3)	21	1.15	0.12	58	1.14	0.14	0.18	0.4308
Macroporosity (%)	20	16.16	4.87	58	15.93	4.66	0.19	0.4265
Microporosity (%)	20	36.11	4.75	58	37.16	4.15	-0.88	0.1917
Total porosity (%)	20	52.27	2.98	58	53.09	4.14	-0.96	0.1719
Saturated Hydraulic Conductivity (cm/hr)	16	2.87	4.05	54	2.60	4.44	-0.29	0.4103

Other studies have reported similar results. Hatchell and Ralston (1971) found that over time, soils can recover during repeated wetting and drying cycles which tend to improve the soil structure, thus ameliorating the soil damage. They report that over a two year period, compacted soils formed a platy structure as a result of wetting and drying cycles, and that plant roots entered cracks in the soil. Hatchell and Ralston (1971) also found that earthworms and grass were a positive soil ameliorator. It appears that both earthworms and heavy grass cover on the skid trails have helped to ameliorate the overall properties of the soils in the Demonstration Area. In Oregon, Snider and Miller (1985) measured the physical properties of silt loam soils six years after logging and found that soil density, organic matter and water conductance were not altered by the logging operation compared to non-logged control sites. Therefore, either no soil damage occurred after thinning or the soils in the Demonstration Area have been ameliorated during the four years since thinning occurred. This would account for the similarity of bulk density, macroporosity and saturated hydraulic conductivity for both the undisturbed and disturbed areas.

Values of soil core samples taken from the main skid trails were tested to determine if soil physical properties changed as the distance from the deck increased. The samples from transect line 1 (the area closest to the deck, which received the most machine traffic) were compared to the samples collected on transect lines 2-7.

The only significant difference in bulk density values occurred between the soils on the first and fourth transect lines. The bulk density on the fourth line (1.09 Mg/m^3) was significantly lower ($p=0.10$) than that on transect line one (1.18 Mg/m^3) (Table 4.2). None of the other transect lines had bulk densities which were significantly different from those of the transect line 1 soils. Furthermore, none of the soils sampled on the transect lines of the Demonstration Area contained bulk densities thought to be detrimental to tree growth (Table 4.2).

The saturated hydraulic conductivities found on each of the transect lines in the Demonstration Area correlate with the other soil physical parameters (i.e. macropore percentage) of the transect lines and should not effect tree growth. The saturated hydraulic conductivities of soils on transect lines 3 and 6 were significantly lower ($p=0.10$) than the saturated hydraulic conductivity of the first transect line (Table 4.2). The low saturated hydraulic conductivities on these two transect lines may have resulted from slightly higher clay contents in these areas.

Table 4.2. Bulk density and saturated hydraulic conductivity by transect line of the disturbed soils in the Demonstration Area.

	Bulk Density (Mg/m^3)	Saturated hydraulic conductivity (cm/hr)
Transect line 1	1.16	5.04
Transect line 2	1.15	1.84 +
Transect line 3	1.12	1.53 *
Transect line 4	1.08 +	4.29
Transect line 5	1.23 +	1.65 +
Transect line 6	1.11	1.29 *
Transect line 7	1.13	2.29

* Denotes value is significantly different from transect line 1 values at p=0.10
+ Denotes value is significantly different from transect line 1 values at p=0.15

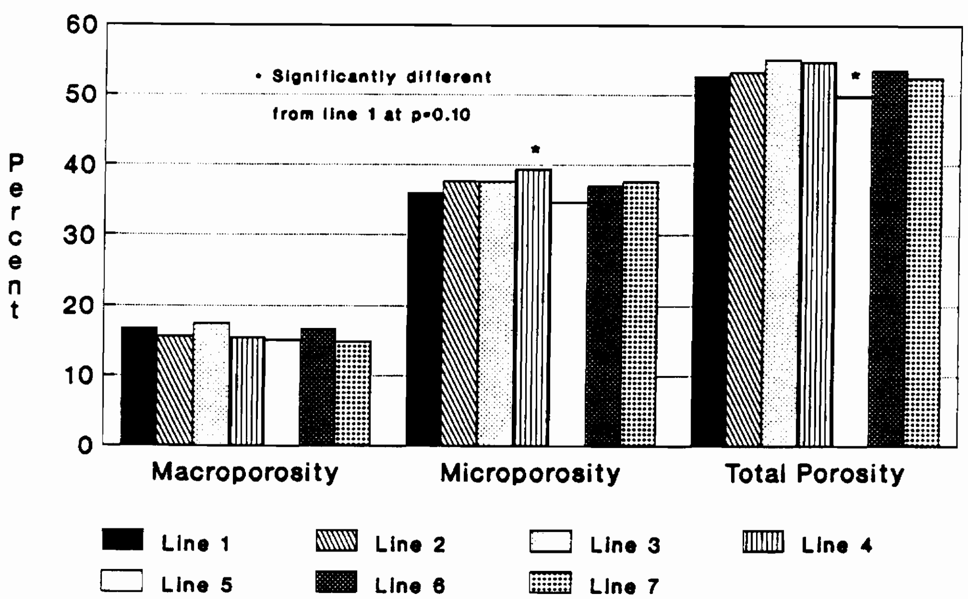

Figure 4.1. Averages of the soil physical properties by transect line of the disturbed soils in the Demonstration Area.

The total porosity of the soils on the skid trails varied by only 9.7% among all of the transect lines (Figure 4.1). The only significant difference in total porosity occurred between the first and the fifth transect line which had 5.7% less total pore space than the first transect line ($p=0.04$). Macroporosity was also above the 10% minimum needed for healthy tree growth (Froehlich 1980). Transect line 3 had the highest macropore percentage, but it was not significantly different from that of the other transect lines. Similarly, soils on all of the transect lines had approximately equal microporosities. The only significant difference in microporosity occurred between the first transect line (36.1%) and the fourth transect line (39.4%), statistically different at the $p=0.09$ level (Figure 4.1). Brady (1984) stated that a soil ideal for plant growth would contain 50% solid soil particles, 20-30% water, and 20-30% air. The porosities of the Demonstration Area's soils allowed the soils to hold sufficient amounts of air and water for plant growth; therefore, none of the transect lines contained porosity levels thought to detriment tree growth (Figure 4.1).

In addition, soil profile data indicates the average rut depth decreased from 18 inches (transect lines 1 and 2) to approximately 6 inches on transect line 5 (the farthest transect line from the deck). Although slight differences in the soil parameters were noticed as the distance to the deck decreased (and machine traffic increased), the disturbed areas' soil parameters were seldom significantly different from those of undisturbed soils. Neither the undisturbed nor disturbed soils of the Demonstration Area contained soil physical properties detrimental to tree growth. Foil and Ralston (1967) found that loblolly pine root growth was not severely restricted until bulk densities were greater than 1.33 Mg/m^3. In a sandy loam soil, loblolly pine root growth was affected at bulk densities higher than 1.4 Mg/m^3 (Gent et al. 1983). Compared to these findings, the impacts of machine traffic on the soils in the

Demonstration Area suggest that mean bulk density 4 years after mechanized thinning was not enough to affect loblolly pine growth.

DEER CAMP AREA

Approximately twenty-five percent of the Deer Camp Area was trafficked during the mechanized thinning. Instead of compact and uniformly spaced corridors, the number of skid trails and their proximity to one another indicate that the logger followed no guidelines for locating skid trails and did not confine machine traffic to designated skidding corridors. High soil moisture content at harvest time may have forced the logger to traverse more ground to avoid rutting or getting machinery stuck. Visual inspection of the stand indicated that the 95% of the ruts were less than six inches deep.

As shown in Table 4.3, no significant differences in bulk density were found between the undisturbed and disturbed soils of the Deer Camp Area. The bulk density for the undisturbed soils averaged 1.17 Mg/m^3, while the bulk density of the disturbed soils averaged 1.12 Mg/m^3 (Table 4.3). As in the Demonstration Area, the bulk densities measured were much lower than the levels currently thought to restrict root growth. The only other observations of interest in the Deer Camp Area were that the soils in disturbed areas had a lower ($p=0.37$) saturated hydraulic conductivity, a higher macropore percentage ($p=0.03$) and higher total pore percentages ($p=0.14$) than did the soils of the undisturbed areas (Table 4.3).

Table 4.3. Mean values of the soil physical properties in the Deer Camp Area.

	Undisturbed Areas			Disturbed Areas			Statistics	
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	t-value	p-level
Bulk Density (Mg/m^3)	19	1.17	0.21	106	1.12	0.24	1.04	0.1536
Macroporosity (%)	19	9.26	3.41	106	10.97	5.11	-1.84	0.0366
Microporosity (%)	19	33.53	5.72	106	33.73	7.06	-0.139	0.4452
Total Porosity (%)	19	42.79	6.73	106	44.71	8.41	-1.096	0.1410
Hydraulic Conductivity (cm/hr)	18	4.25	8.94	96	3.50	6.63	0.339	0.3686

Earthworms were found in many of the disturbed soil samples and the skid trails were grassed over; both factors probably increased the amount of macropore space within the samples. As macropore space increases, the saturated hydraulic conductivity of the soil also increases and the bulk density decreases. Both earthworms and grass were cited by Hatchell and Ralston (1971) as beneficial to soil structure. These factors, plus the wetting and drying cycles since thinning, could have sufficiently ameliorated the damaged soils by the time the measurements were taken five years after thinning. The other possibility is that the soils of the Deer Camp Area were not damaged during the thinning operation.

Hatchell and Ralston (1971) state that soils in open areas tend to recover faster than soils under heavy forest vegetation. We found this to be true for this study area. The macroporosity of the soils in the Deer Camp Area were 14.4% for the undisturbed areas, and 16.7% for the disturbed soils (Table 4.3). Froehlich (1980) states that less than 10% macroporosity at field capacity could result in growth reductions because the soil is incapable of exchanging adequate amounts of oxygen with the atmosphere. Soils on both the undisturbed (38.4%) and disturbed (38.3%) areas had approximately the same amount of micropore space.

When comparing the Deer Camp Area soil physical properties by distance from the deck (i.e. by transect line), the higher line numbers were associated with less frequently traveled skid trails. In general soil disturbances became more pronounced as the distance from the log deck increased. Comparisons of the first line with the second line show that the second line has significantly higher ($p=0.01$) bulk density (Table 4.4). The second line contained most of the main skid trails leading to the deck and crossed through the area containing the deepest ruts. The bulk density (1.25 Mg/m^3) of transect line 2 did not exceed the 1.3 Mg/m^3 level typically thought to reduce loblolly pine root growth (Foil and Ralston 1967), and was 10.7% below the 1.4 Mg/m^3 level that Gent et al. (1983) found to reduce loblolly pine root growth. Although line 1 was closest to the deck, it had the fewest number of heavily traveled skid trails. Also, the main skid trails that crossed transect line 2 were grassed over and very open, perhaps allowing amelioration processes to occur faster. The bulk density of the third and fourth transect lines were also significantly higher than the bulk density of the first transect line (Table 4.4). As in the Demonstration Area, the bulk densities of the disturbed areas in the Deer Camp Area were not high enough to affect tree growth.

The saturated hydraulic conductivities of the soils on individual transect lines varied from 0.69 cm/hr on the second transect line to 7.15 cm/hr on the third transect line (Table 4.4). The saturated hydraulic conductivity of the third and fourth transect lines were significantly higher ($p=0.01$) than the saturated hydraulic conductivity of the first transect line. Like the Demonstration Area, residual trees should not be affected by the hydraulic conductivities found in the Deer Camp Area.

Table 4.4. Bulk density and saturated hydraulic conductivity by transect line in the Deer Camp Area.

	Bulk density (Mg/m^3)	Saturated hydraulic conductivity (cm/hr)
Transect Line 1	0.92	1.13
Transect Line 2	1.25 *	0.687
Transect Line 3	1.09 *	7.15 *
Transect Line 4	1.12 *	4.68 *

* Denotes statistically significant from transect line 1 values at p=0.10.

Figure 4.2 compares the porosity percentages of the disturbed soils by transect line. The higher line numbers were associated with less frequently traveled skid trails. Transect line 1 had significantly greater total pore space (61.6%) than transect line 2 (50.9%), statistically significant at a p-level of 0.002. Transect line 1 also had 19.3% more micropores than transect line 2, statistically significant at a p=0.0006 level. Likewise, transect line 1 had higher percentages of total pore space and micropores than transect lines 3 and 4, significant at a p=0.07 level. Transect line 1 has 18.9% less macropore space than transect line 3, but significantly more micro- and total pore space (p=0.07). The fourth transect line has 14.8% more macropore space than the first transect line,but had significantly less micro and total pore space (p=0.04).

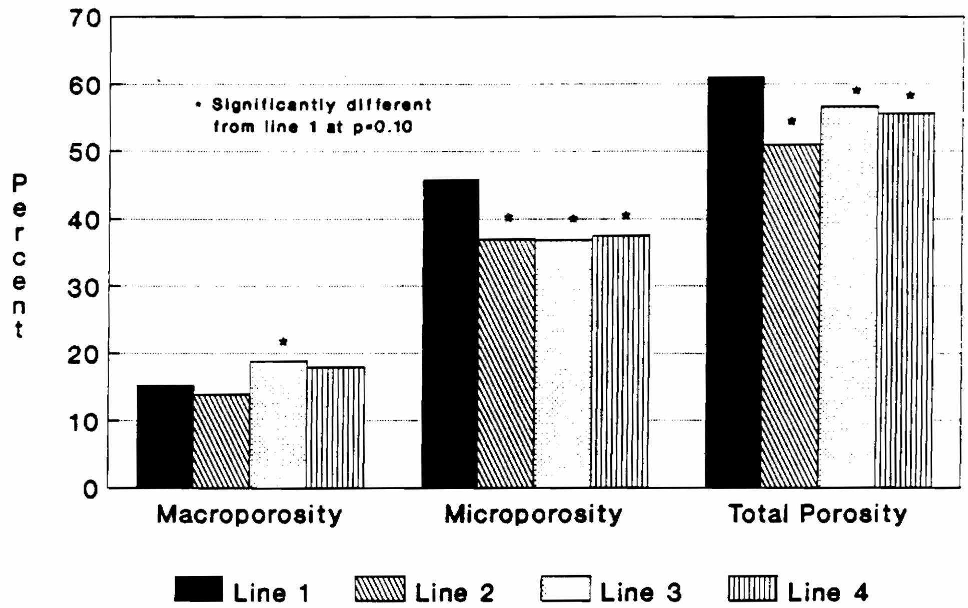

Figure 4.2. Averages of the soil physical properties by transect line of the disturbed soils in the Deer Camp Area.

All of the transect lines contained more macropore space than needed to maintain adequate air exchange with the atmosphere (Karr et al. 1987). Karr and Guo (1991) found macroporosity rates of approximately 12% on the skid trails, and they state that in field conditions, "... that the narrow bands of compaction in this study controlled competition and created a microenvironment that was more favorable to tree growth than what was available for the trees growing in the control plots..." All transect lines had macroporosity percentages greater than 12% and more than 35% micropores.

Based on a review of the literature, soil physical properties in these skid trails in their present condition should not affect tree growth.

The Deer Camp Area soils may have impeded drainage because of the loss of macropore space, but the soils probably are not sufficiently disturbed to reduce tree growth. The large number of micropores possibly could benefit tree growth during the dry season by retaining larger amounts of tree-available water. Indeed, Karr and Guo (1991) found that when skidding on wet sandy loam soils, the bulk density (1.4 Mg/m^3) and microporosity percentage (29%) increased, resulting in decreased macropore space (approximately 12%). Despite the increase in bulk density and decrease of macropore space, these impacts did not reduce growth of loblolly pine during the three year study period (Karr and Guo 1991).

SUMMARY

Both the Demonstration and the Deer Camp Areas have skid trails that have undergone 4-5 years of wetting and drying cycles, are currently grassed over, and based on laboratory observation seemed to be well colonized by earthworms and other soil invertebrates. The soil characteristics measured suggest that if soil conditions immediately after mechanized thinning retarded root growth, then those conditions have ameliorated during the 4-5 years since thinning.

Both study sites contained several areas with ruts greater than six inches deep, but no negative impacts were apparent in the data. These ruts appear to hold water throughout most of the year. Although the soil physical properties of these ruts do not suggest impaired root growth, the air/water space may act as a barrier to root growth and sub-surface drainage, thus changing the micro-site immediately adjacent to the rut.

However, the bulk densities of the soils in both the Demonstration and Deer Camp Area were within the range acceptable for loblolly pine growth.

Overall, the soil survey found that certain sections of the study areas may be adversely affected by the existence of deep ruts, but the condition of the majority of the study areas' soils do not suggest that mechanized thinning permanently damaged these sites. At the micro-site level, these ruts may even improve growth by storing water for a longer period during the dry season and reducing the time trees adjacent to these ruts are under water stress (Karr and Guo 1991). The present condition of the soils on these sites should not adversely affect the growth of loblolly pine.

CHAPTER 5

RESULTS AND DISCUSSION -- RESIDUAL TREE GROWTH

This chapter presents and discusses the results of the post-thinning evaluation of residual tree growth for the two study areas in Grant County, Arkansas. The discussion begins with a general comparison of tree growth for the Demonstration and Deer Camp Areas, and then progresses to more detailed comparisons of the growth effects by soil disturbance level. The first section of the chapter deals with the Demonstration Area and the second section deals with the Deer Camp Area.

DEMONSTRATION AREA

The Demonstration Study Area was a 1.9 acre portion of a twenty-six year old natural loblolly pine stand that was corridor thinned four years earlier (i.e. 1988). The mechanized thinning operation placed corridors approximately forty feet apart, and removed trees located between the corridors by single tree selection (Figure 5.1). The diameter distribution of the 341 trees measured in the Demonstration Area ranged from three to eighteen inches DBH (diameter at breast height)(Figure 5.2). Because the diameter distribution of trees was extremely varied, both parametric and non-parametric methods were used to analyze the data. The non-parametric statistics served to confirm the results of the parametric t-tests.

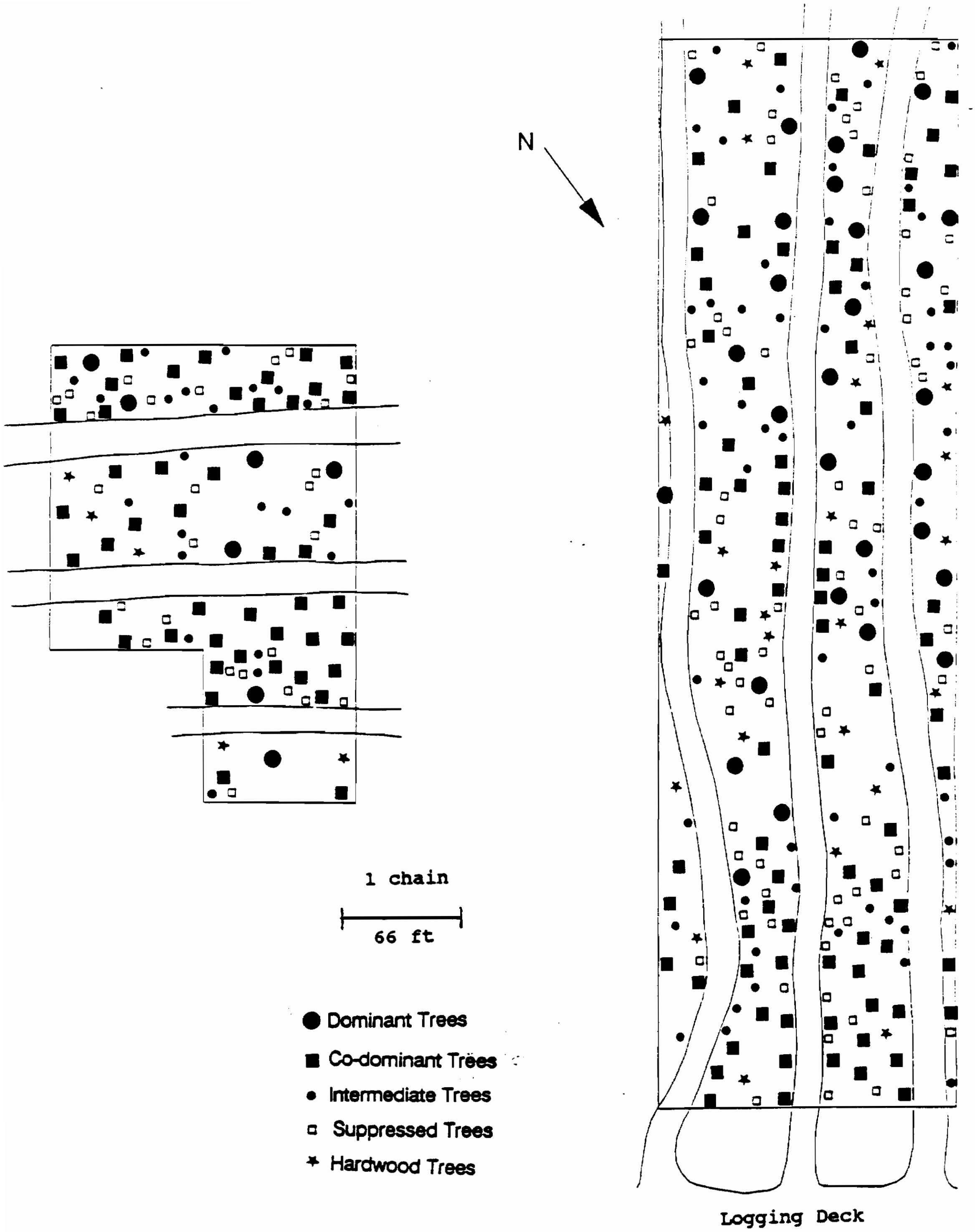

Figure 5.1. Map of Demonstration Area showing skidtrails and residual tree spacing.

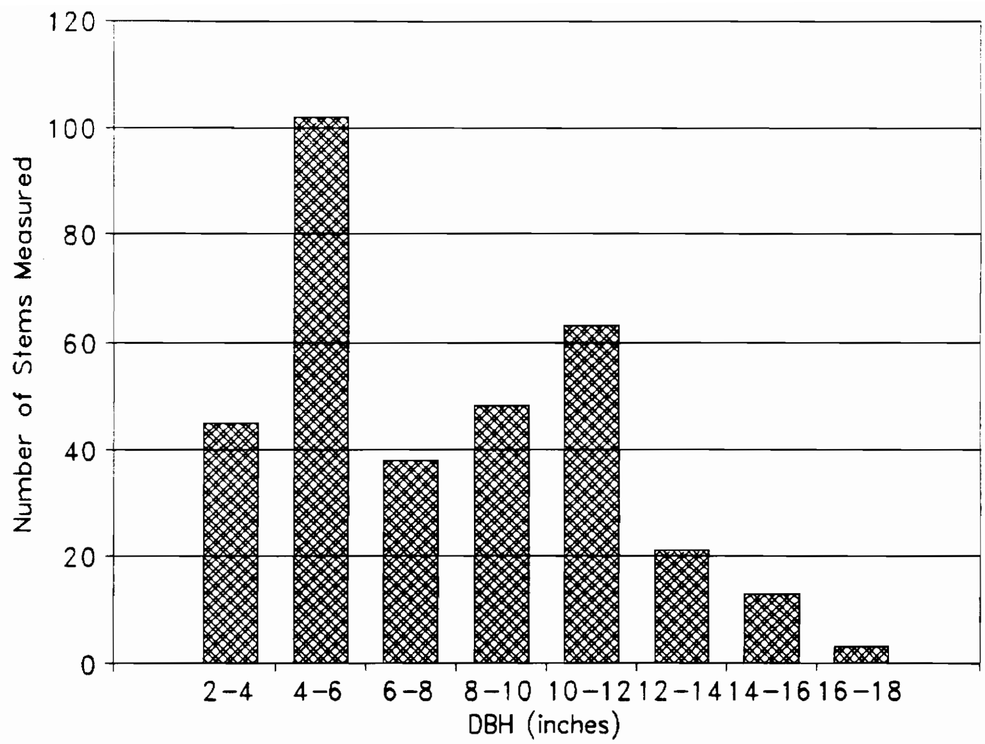

Figure 5.2. Diameter distribution of trees measured in the Demonstration Area.

Overall Stand Response to Thinning

The central question of the study was whether the trees adjacent to the corridors were impacted by machine traffic near their root systems during the mechanized thinning operation. The first step in this process was to compare the stand's periodic annual increment (PAI) for the 5-7 years before thinning with their PAI 4 years after thinning. The annual radial growth increased 0.23 mm or 7.2% after thinning (Table 5.1). This radial growth was significantly different than growth prior to thinning at a $p=0.07$ level.

Table 5.1. PAI of trees in the Demonstration Area 5-7 years before and 4 years after thinning.

PAI Before Thinning			PAI After Thinning		Statistics	
N	Mean	Std. Dev.	Mean	Std. Dev.	t-value	p-level
347	2.89 mm/yr	1.16	3.12 mm/yr	1.44	-1.44	0.0747

Other studies have found that radial growth of loblolly pine will increase more than 20% after thinning. Basset (1964) thinned a 30 year-old loblolly pine stand at two different intensities (i.e. basal areas of 12.6 m^2/ha and 28.7 m^2/ha) and found that the stand thinned to the lower residual basal area outgrew the other stand by 40.7% over four years. The Demonstration Area was thinned at an earlier age (approximately 22 years old), but did not respond at rates comparable to those cited in the literature. This lack of response may result from inadequate thinning in parts of the stand, which failed to increase the amount of available crown space for the trees in those areas (Figure 5.1). The low site index of the Demonstration Area (50 at base age 25) could also partially explain the low thinning response in this area. Changes in soil physical properties may also be an explanation, however, the soil physical properties found in the Demonstration Area do not appear to have negative effects on loblolly pine growth (Chapter 4).

Comparison of Thinning Response Based on Distance to the Skidding Corridor

To determine if the machine traffic impacted the growth of loblolly pine in the Demonstration Area, the data was divided into two distance zones. The first zone included trees growing within 12 feet of the corridor, and the second zone included trees growing farther than 12 feet from the corridor. Two-sample t-tests using the Welch Approximation (i.e. assumed unequal and unknown variances) (Ott 1988, Hintze 1990) were used to test the growth responses of the trees 0-12 feet from the corridor against those of trees growing more than 12 feet from the corridor. Multiple parameters were tested: diameter at breast height, total tree height, height to the base of live crown, crown class, crown width, radial growth from tree origination (pith) to time of thinning, radial growth of each year after thinning, and age. Appendix A contains the means, standard deviations, and statistical results of these tests.

The results of these tests were mixed. The DBH of trees closest to the corridors (i.e. 0-12 feet from corridor) exceeded the DBH of the trees growing more than 12 feet from the corridor before and after thinning (Appendix A Table 1). However, this difference in DBH was not statistically significant, and may be partly explained by a one year age difference between the two groups. Before thinning, the trees 0-12 feet from the corridor were growing faster than those more than 12 feet from the corridor at all measured radial growth points. The radial growth of the trees growing 0-12' from the corridor 11-15 years after stand establishment was significantly higher than the radial growth of the trees growing in the >12' areas at a $p=0.02$ level. From 16-20 years after stand establishment, the growth of trees located 0-12 feet from corridor was greater than the growth of trees in the >12' areas at a

$p=0.12$ level. From 21-25 years after stand establishment, the trees 0-12 feet from the corridor grew faster than the trees growing more than 12 feet from the corridor at a $p=0.10$ level. Therefore, the growth from pith to age of thinning of the trees growing 0-12 feet from the corridor was statistically greater than the trees growing more than 12 feet from the corridor at a $p=0.03$ level.

After thinning, the radial growth of trees 0-12 feet from the corridor continued to increase faster than that of trees located more than 12 feet from the corridor (Figure 5.3). Tree growth 0-12 feet from the corridor differed significantly ($p=0.04$) from tree growth in areas located more than twelve feet from the corridor (i.e. >12' areas) the third year after thinning. The total radial growth after thinning (13.52 mm) for the trees 0-12 feet from the corridor was significantly larger than the total radial growth in the >12' areas (11.83 mm) for the 4 years after thinning at a $p=0.02$ level (Appendix A Table 1). Tree age was also significantly different: the trees growing 0-12' from the corridors averaged one year older than the trees growing in the >12' areas ($p=0.01$). This difference in tree age suggests that the smaller trees within 12 feet of the corridor were removed, leaving the larger faster growing trees. These fast growing trees reach DBH faster than smaller trees and thus tend to appear older than the surrounding trees.

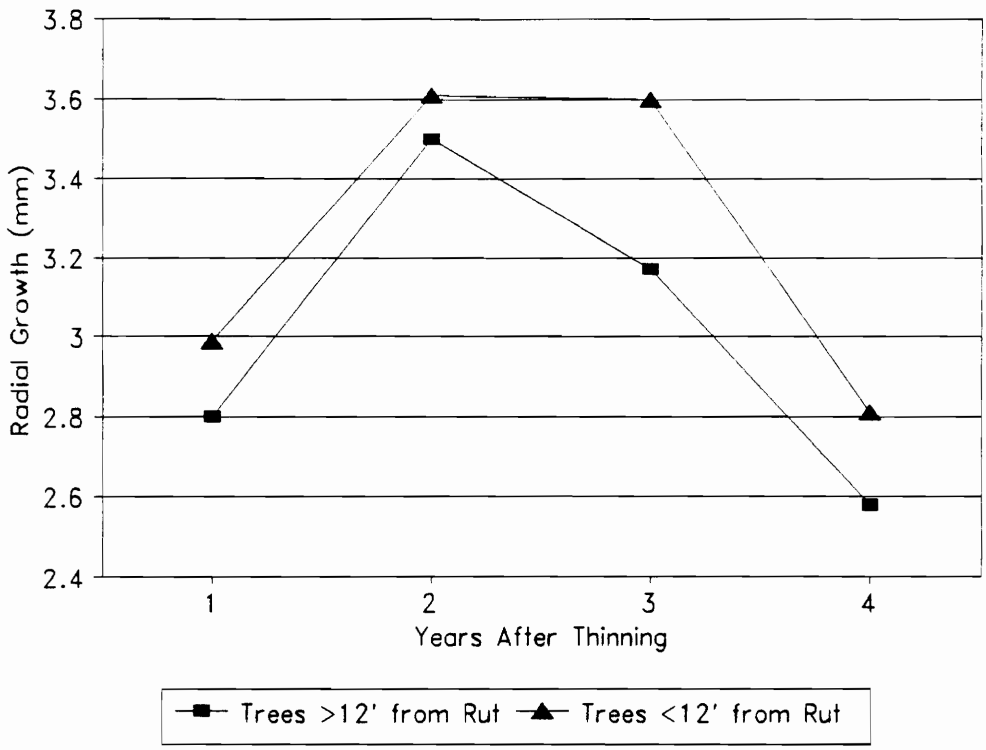

Figure 5.3. Annual radial growth after thinning for trees in the > 12' and 0-12' areas of the Demonstration Area.

Because the measured parameters of trees in the 0-12' and > 12' areas had extremely large variances, there was some concern that the previous testing procedure did not completely describe the effects of the soil disturbance on loblolly pine growth. Thus, the trees 0-12' from the corridor were divided into two smaller samples: trees within 6 feet of the rut (i.e. 0-6' areas), and trees growing 6 to 12 feet from the rut (i.e. 6-12' areas). This sub-division of the data reduced the variances within the previous classes and provided a more powerful statistical test. The hypothesis was that the growth of the trees closest to the corridor would equal the growth of trees located farthest from the corridor. Two-sample t-tests were used to compare tree growth in the > 12' areas, 0-6' areas, and 6-12' areas.

The results from these comparisons were mixed, but in 0-6' areas, tree growth after thinning exceeded post-thinning growth of the trees in the > 12' areas. Comparison of the periodic annual increment (PAI) 5-7 years before thinning with the PAI 4 years after thinning indicated that trees growing within 12 feet of the corridor had higher growth rates than trees growing in the > 12' areas. After thinning, the trees in the > 12' areas grew 0.03 mm slower per year than they did before thinning, a result that was significantly different at a $p=0.03$ level (Figure 5.4). However, the trees growing in 0-6' areas grew 13% faster after thinning, significantly different at a $p=0.08$ level. The radial growth of the trees in 6-12' areas was also significantly higher than their growth before thinning at a $p=0.09$ level, by 11.3%.

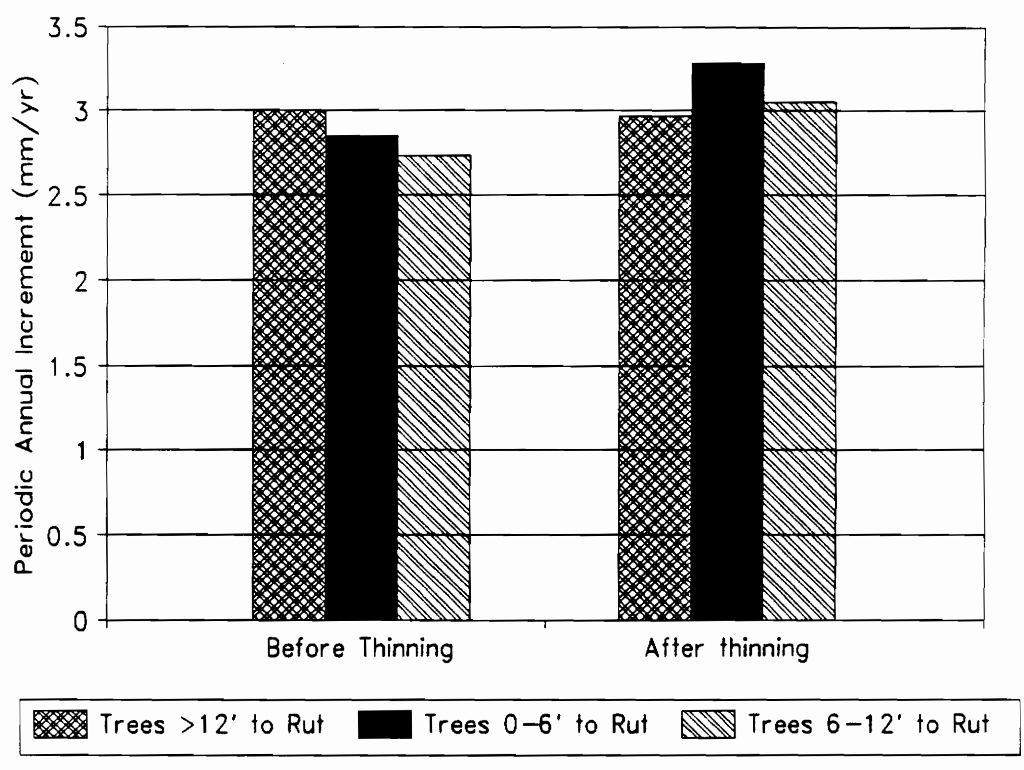

Figure 5.4. Comparison of PAI 5-7 years before thinning and 4 years after thinning for the > 12', 0-6', and 6-12' areas of the Demonstration Area.

Comparison of Growth in >12' versus 0-6' Areas

Comparisons of growth before and after thinning indicated that all trees responded positively to the thinning, but those comparisons did not show the response within each disturbance category. The PAI (5-7 years before thinning) of the trees growing in the >12' areas was compared with the PAI of the trees growing in 0-6' areas. The trees in the >12' areas had a slightly higher (5.1%) PAI before thinning than those in 0-6' areas, but these results were not significantly different at a $p=0.10$ level (Figure 5.4).

After thinning, however, the trees in the 0-6' areas responded with faster growth than the trees in the >12' areas. The trees growing in 0-6' areas averaged 3.3 mm of radial growth per year, whereas the trees growing in the >12' areas averaged 2.97 mm per year ($p=0.11$) (Figure 5.4). The mean annual increment (MAI) of the trees in 0-6' areas was 6.8% larger than the MAI of trees in the >12' areas, significant at a p-level of 0.13.

Individual comparisons were also performed on other tree parameters, such as DBH and total height. The DBH and total height of trees in the 0-6' areas were not significantly different ($p=0.45$) from those in the >12' areas (Appendix A Table 2). Trees in the 0-6' areas had 8.8% wider crowns than the trees in the >12' areas, significant at a $p=0.11$ level. The trees in 0-6' areas outgrew the trees in the >12' areas before and after thinning. From the period 11 to 15 years after stand establishment, the trees growing in 0-6' areas grew 10.1% more (2.2 mm) than did the trees growing in the >12' areas; these differences were significant at a $p=0.07$ level. During the next five year period (16-20 years after stand establishment), the radial growth of the trees in 0-6' areas was significantly larger (p=0.14) than that of the trees in the >12' areas.

The trees in the 0-6' areas also grew faster each of the four years after thinning. However, the only significant difference for a single year's growth (p=0.09) occurred the first year after thinning. Over the four year period after thinning, the trees in the 0-6' areas outgrew the trees in the >12' areas by 1.49 mm, a difference significant at the p=0.06 level. The trees in 0-6' areas, however, were one year older than the trees growing in the >12' areas, significant at a p=0.02 level (Appendix A Table 2).

The data indicate that the trees in 0-6' areas apparently were not negatively affected by the machine traffic and rutting in the corridors, and the overall response to thinning was positive. The poor performance of the trees in the >12' areas may indicate that these areas were not adequately thinned. Increasing the number of trees removed from the >12' areas may have allowed those crop trees to respond at rates similar to those of the trees in 0-6' areas (Figure 5.1). Since tree growth in 0-6' areas was not impacted by the close proximity of machine traffic, the selectively thinned areas (i.e. >12' and 6-12' areas) probably could be thinned more heavily without damaging the growth potential of the residual trees.

Comparison of Tree Growth in >12' versus 6-12' Areas

Although, the differences were smaller, trends similar to those in the preceding comparison were found when growth of the trees in the >12' (trees located more than twelve feet from the rut) and 6-12' areas (trees located 6-12 feet from the rut) were compared. The trees growing in the >12' areas had a higher PAI for the 5-7 years before thinning than did the trees in the 6-12' areas (3.00 mm and 2.73 mm, respectively) (Figure 5.4, Appendix A Table 3). However, the 0.27 mm difference in radial growth was not statistically significant at a $p=0.10$ level. This trend was reversed after thinning: the trees growing in 6-12' areas grew 3.17 mm per year, whereas the trees in the >12' areas grew 2.97 mm per year. The growth in the 6-12' areas were 6.3% faster than tree growth in the >12' areas after thinning ($p=0.23$). The trees growing in 6-12' areas also had a higher overall MAI (3.7 mm/yr) than the trees growing in the >12' areas (3.4 mm/yr), significant at a $p=0.14$ level.

The trees growing in 6-12' areas grew faster before and after thinning than the trees in the >12' areas. However, the only significant difference in growth before thinning was in the period 11-15 years after stand establishment. During this period, the trees growing in 6-12' areas grew 3.61 mm more than the trees growing in the >12' areas, a difference significant at a $p=0.04$ level (Appendix A Table 3).

The only significant difference in radial growth occurred the third year after thinning. The trees growing in 6-12' areas grew 4.38 mm, but the trees growing in the >12' areas grew only 3.17 mm, significant at a $p=0.07$ level (Appendix A Table 3). These differences in growth before and after thinning resulted in average diameters of 7.5 inches for trees growing in 6-12' areas and 7.39 inches for trees growing in the >12' areas ($p=0.42$).

Although the growth rates before thinning differed slightly, no strong trends were apparent. After thinning, the trees in 6-12' areas consistently produced more radial growth than the trees growing in the >12' areas. This strong radial growth response after thinning indicates that the trees growing in 6-12' areas did not suffer direct impacts from soil disturbance. This thinning response also suggests that crown space and competition may be more limiting than the soil disturbance in this area. As mentioned earlier, differences in growth response were probably caused by more efficient thinning in the areas closest to the corridors.

The results of the non-parametric analysis supported the same trends as the previous analysis and are discussed in Appendix B. An additional discussion of tree growth based on diameter class and crown classification can be found in Appendix C.

Comparison of Tree Growth by Depth of Rut

The majority of the corridors had bulk densities ranging from 1.08 to 1.23 Mg/m^3, and it was assumed that the trees located adjacent to most corridors did not experience growth reductions resulting from machine compacted soils. The trees located near the deepest ruts, however, may have incurred root damage during trafficking which caused growth to decline after thinning. The ruts may have also interrupted sub-surface drainage, potentially flooding the root system during wet periods and contributing to a loss of vigor and a subsequent decline in growth.

To test this hypothesis, the trees 0-12 feet from rut were separated into the following categories based on rut depth: 0-3 inches, 3-6 inches, and 6-24 inches. Although the sample size was small ($N=11$), the analysis showed that the trees next to the deepest ruts were some of the largest trees in the stand. Appendix D contains the means, standard deviations and statistical results for these tests.

Comparison of Radial Growth by Depth of Rut

As illustrated in Figure 5.5, the radial growth (PAI) of trees growing more than 12 feet from the corridor during the 5-7 years before thinning was greater than for trees growing in areas where the ruts were 0-3 inches and 3-6 inches deep. Before thinning, the trees growing in the areas more than 12' from the rut grew 10.7% faster than the trees next to 0-3 inch ruts and 13.7% faster than trees located next to 3-6 inch ruts, both significant at $p=0.11$. The trees adjacent to ruts deeper than 6 inches outgrew those >12' from the rut by 13.1% during the same period ($p=0.14$) (Figure 5.5).

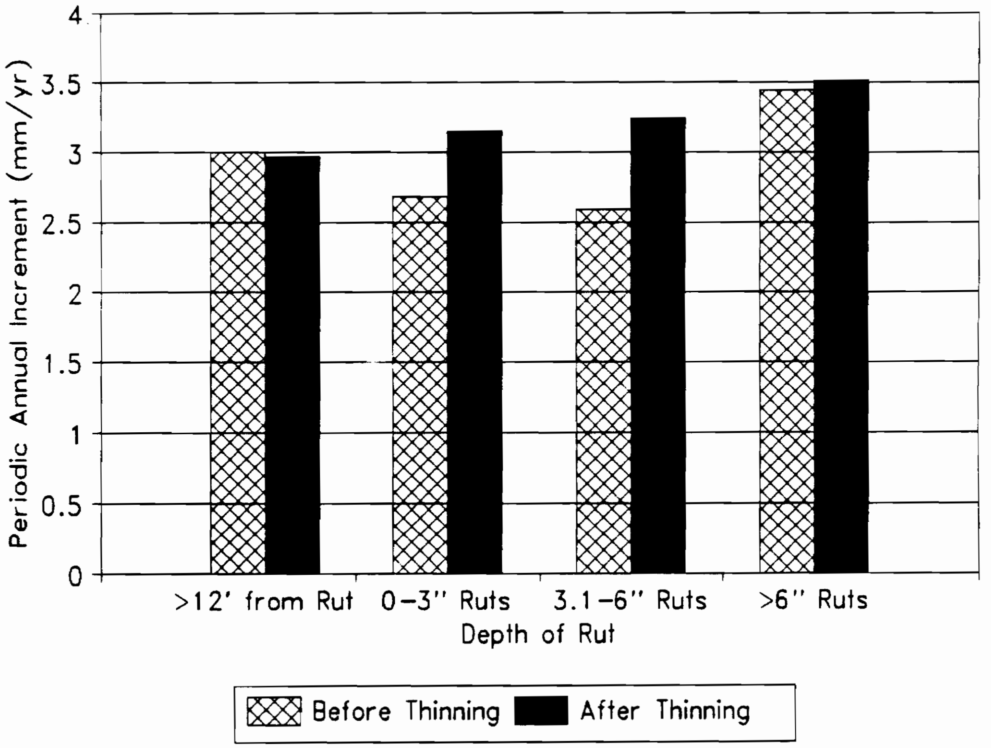

Figure 5.5. PAI (mm/yr) for the 5-7 years before thinning and 4 years after thinning for the trees in >12' areas and trees adjacent to ruts 0-3",3-6", and 6-24" deep.

After thinning, all trees growing in the disturbed areas, regardless of rut depth, had higher radial growth rates than those found in the > 12' areas. The fastest growth occurred for trees adjacent to the deepest ruts (> 6 inches) before and after thinning (Figure 5.5). After thinning, the trees growing in the > 12' areas averaged 2.97 mm of annual radial growth, while the trees on ruts deeper than 6 inches averaged 3.49 mm, a 15% growth increase statistically significant at a $p=0.10$ level.

These results, however, were somewhat misleading. A comparison of growth rates before and after thinning for each rut depth revealed that the trees on ruts deeper than 6 inches increased their annual growth at a much slower rate (0.04 mm per year) than did trees growing on shallower ruts (Figure 5.6). Perhaps, the trees growing adjacent to the deepest ruts received more complete crown release, but failed to capitalize on the increased growing space; or perhaps these trees were growing near their maximum rates before thinning and could only increase their growth slightly after thinning. The trees growing on 3-6 inches inch ruts responded best to thinning, increasing their radial growth rate 0.66 mm per year after thinning, and the trees on 0-3 inch deep ruts responded second best, increasing growth by 0.47 mm per year. In contrast, the trees growing in > 12' areas actually grew slower after thinning than they did before thinning.

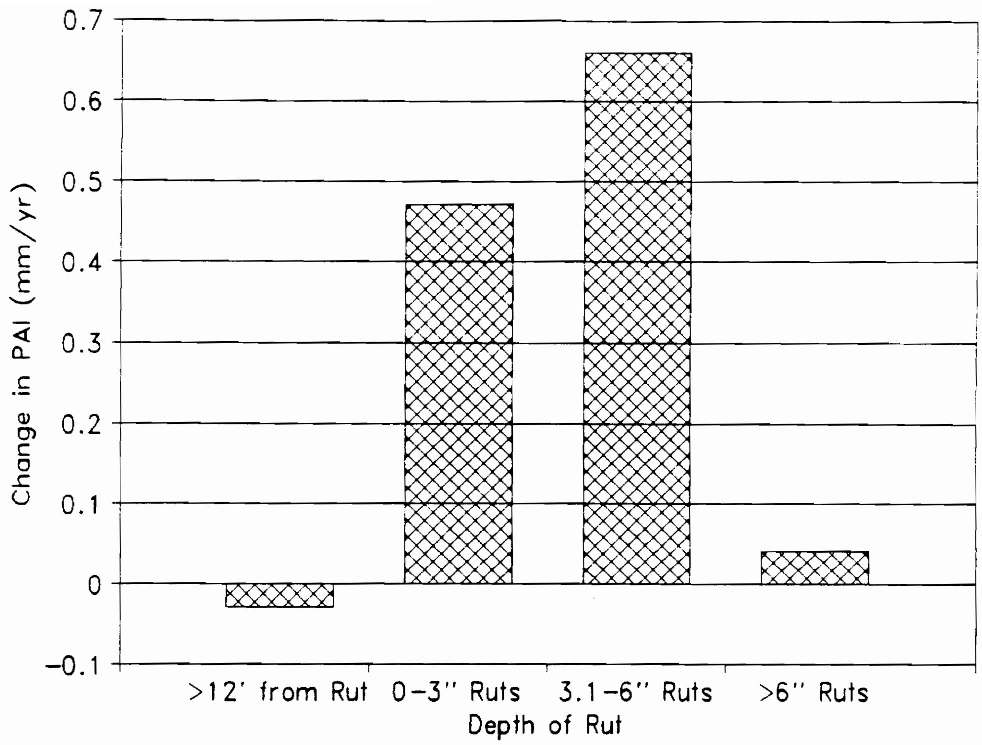

Figure 5.6. The change in radial growth rates before and after thinning based on depth of rut.

Comparison of Other Tree Parameters Based on Rut Depth

After evaluation of thinning response, diameter, total height, and periodic growth of the trees in each disturbance class were compared for the periods before and after thinning. The DBH of the trees growing in the > 12' areas was greater ($p=0.12$) than the DBH of trees near 0-3 inch ruts (Appendix D Table 1). However, the trees on 3-6 inch ruts had larger diameters than the trees growing in the > 12' areas (Figure 5.7). The trees growing on ruts deeper than 6 inches had an average DBH of 8.95 inches, significantly larger than the DBH of trees growing in the > 12' areas (7.4 inches) at a $p=0.13$ level. The total height of the trees in the > 12' (from the rut) areas was 4 feet taller than the trees located adjacent to ruts 0-3 inches deep (p=0.09) (Appendix D Table 1), but the trees on 3-6 inch ruts were almost 3 feet taller than those in the >12' areas (p=0.13) (Appendix D Table 2). Likewise, the trees on ruts deeper than 6 inches were 4 feet taller than the trees located more than 12' from the rut (p=0.20) (Appendix D Table 3). Height to the live crown was not significantly different from that of trees in the >12' areas in any of the rut categories (p=0.10).

The trees located near ruts deeper than 3 inches grew faster than the trees growing more than 12' from the rut before thinning, with the differences increasing as rut depth increased (Figure 5.8). Trees adjacent to ruts 3-6 inches deep significantly outgrew the trees in the >12' areas during the 11-15 years after stand origination (p=0.02). Trees adjacent to ruts deeper than 6 inches outgrew the trees more than 12' from the corridor radially during the 16-25 year period after stand origination at a p=0.06 level.

After thinning, the trees in all rut disturbance categories radially outgrew the trees more than 12' from the corridor (Figure 5.8 and Appendix D). This difference in radial growth of the trees adjacent to 0-3 inch ruts was not significantly different from radial growth of the trees in the >12' areas. However, the trees on ruts 0-3 inches and >6 inches deep grew significantly faster than the trees more than 12' from the corridor at a p=0.08 level.

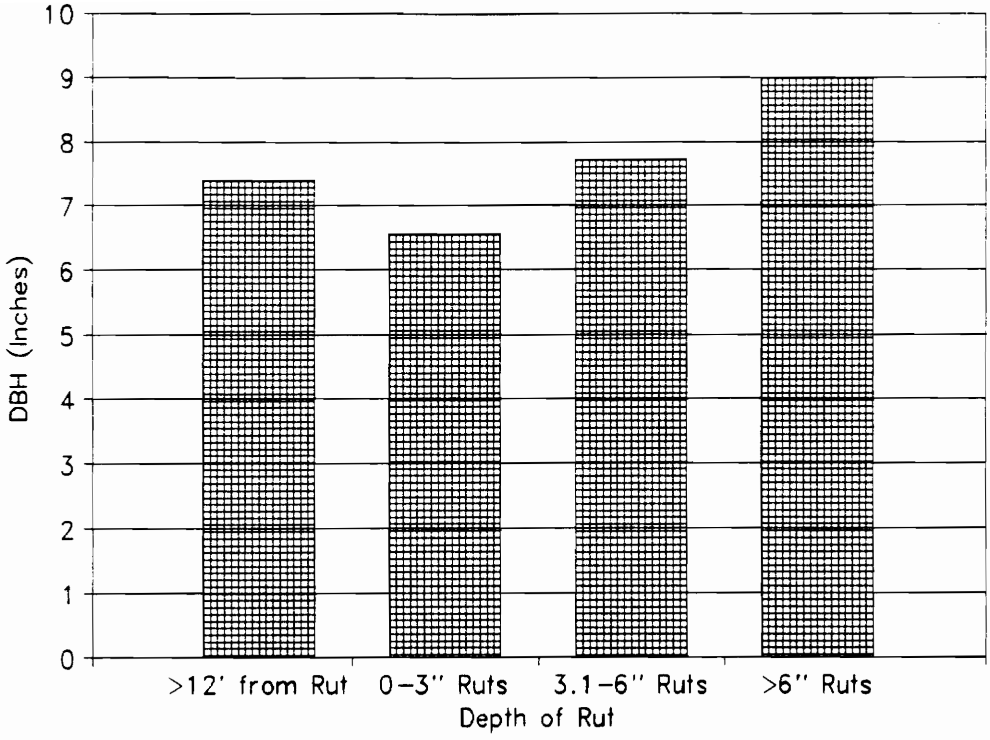

Figure 5.7. DBH of trees more than 12 feet from the corridor and trees 0-12' from corridors on ruts 0-3", 3-6", and 6-24" deep in the Demonstration Area.

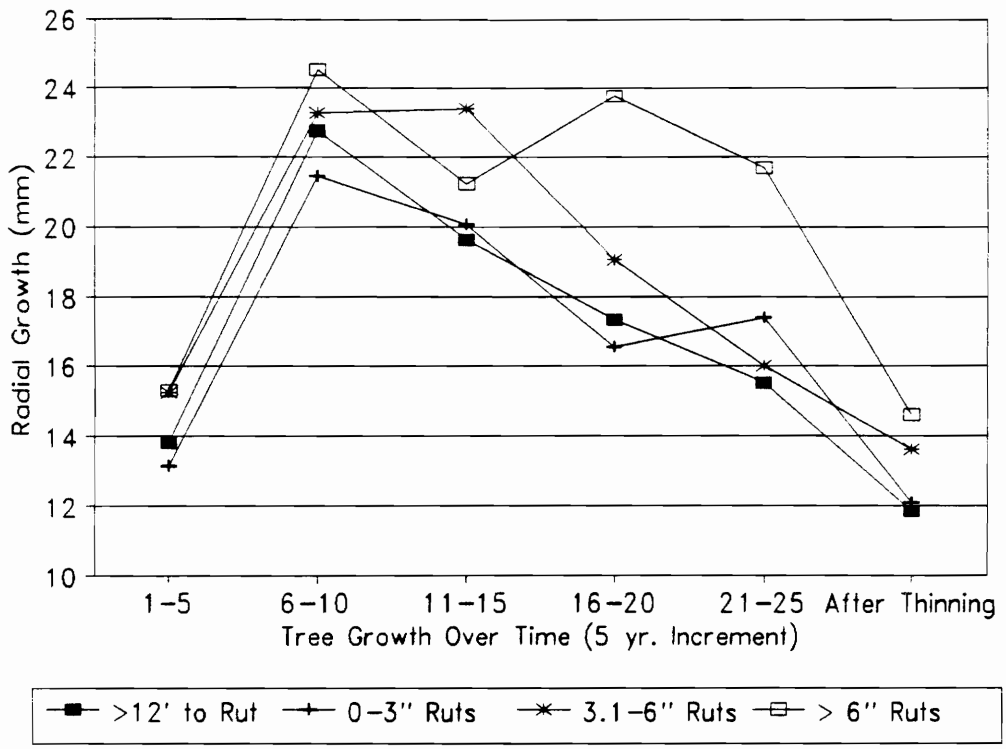

Figure 5.8. Growth of trees in > 12' areas and trees adjacent to 0-3", 3-6", and 6-24" ruts on the Demonstration Area, from stand origination to the end of the study.

Summary

In general, the growth response of loblolly pine in the Demonstration Area was positive, but not as great as might have been experienced if the stand was thinned at an earlier age. Data analysis indicated that the deepest ruts (6-24 inches) reduced the rate of growth of loblolly pine after thinning. Compared with their pre-thinning growth, the trees on the deepest ruts had the poorest response after thinning. However, these trees were also the largest trees in the stand, partly a result of superior growth before thinning. The trees growing near shallow ruts apparently offset any detrimental impact of rutting by utilizing the increased crown space after thinning. The trees growing more than twelve feet from the corridor, however, probably failed to increase their growth because too few of the competing trees were removed.

The main factor influencing tree growth in the Demonstration Area appears to be the quality of the thinning operation. Based on observation during data collection, trees of all diameters were left after thinning; these smaller intermediate and suppressed trees may have failed to increase their radial and height growth immediately after thinning because they first had to rebuild their crown and root systems (Seiler 1991). Such growth responses after thinning produce little increase in the residual stand's net worth.

DEER CAMP AREA

The Deer Camp Area was a 4.0 acre portion of a 31 year old natural loblolly pine stand with a site index of 60 feet (base age 25) that was thinned from below five years earlier (i.e. 1987), leaving a residual crop of 540 trees consisting mainly of dominant and co-dominant loblolly pine with a diameter distribution ranging from 4 to18 inches (Figure 5.9). The many skid trails, large number of trees with basal damage, and the large number of hardwood stems remaining in the stand indicated that this area was not thinned as efficiently as the Demonstration Area (Figure 5.10). The total area with machine traffic was greater in the Deer Camp Area (25%), but the soil data collected (Chapter 4) revealed that the soils were not severely compacted or rutted. Because stand age differed, site index, and quality of thinning differed, no statistical comparisons between study areas were attempted.

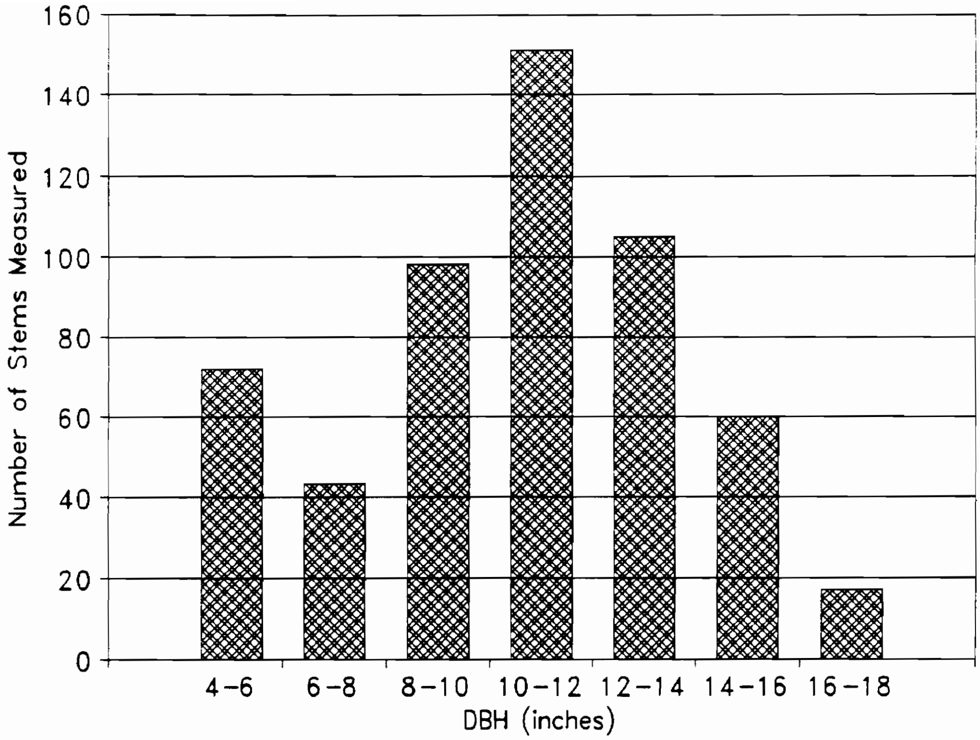

Figure 5.9. Diameter distribution of trees measured in the Deer Camp Area.

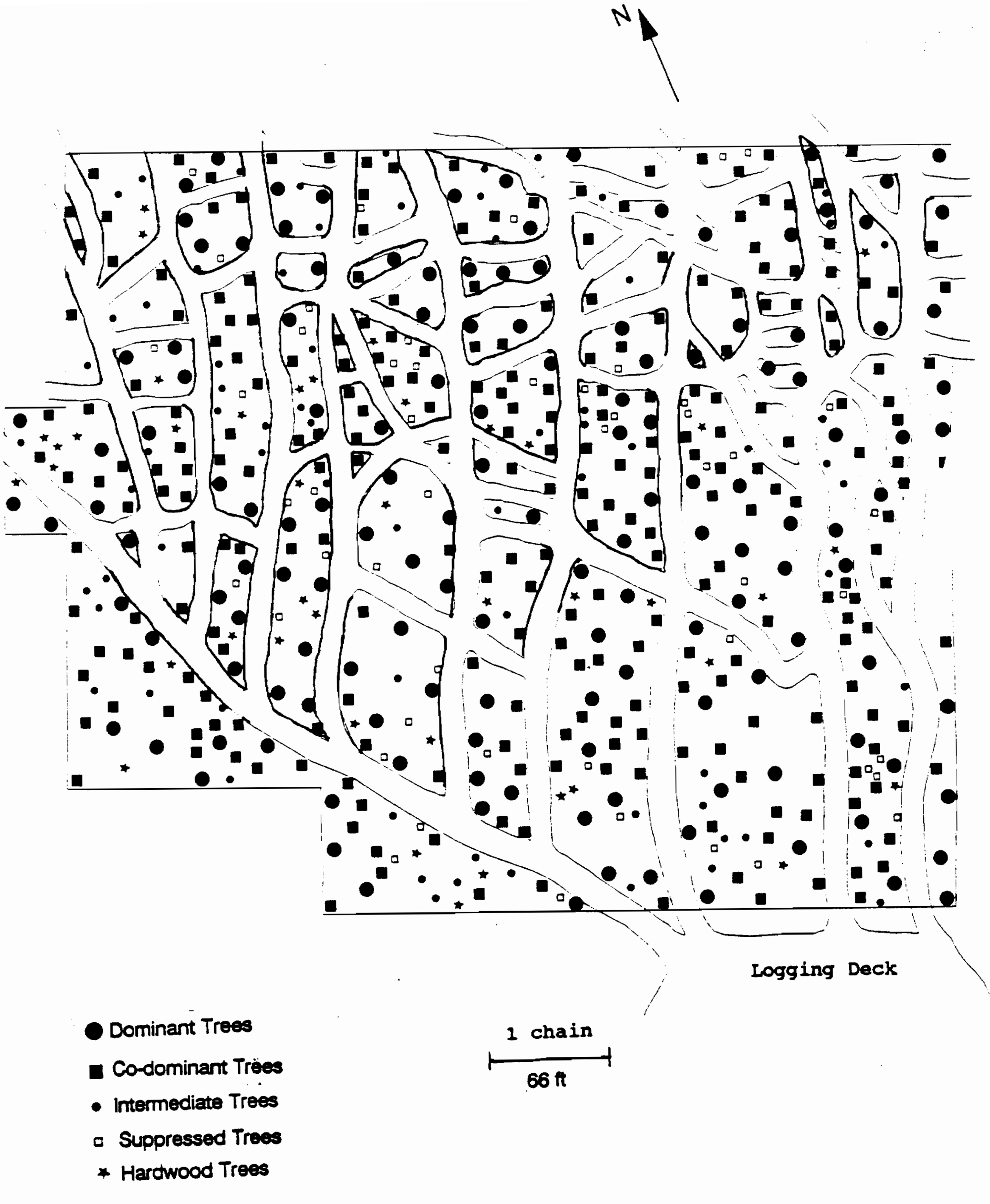

Figure 5.10. Map of Deer Camp Area showing placement of skid trails and residual trees.

Overall Stand Response to Thinning

The same procedure detailed for the Demonstration Area was used to analyze the data from the Deer Camp Area. First, in order to determine the total stand response to thinning, the radial growth (PAI) for the 5-7 years before thinning was compared to the PAI for the 5 years after thinning. The PAI of the trees in the Deer Camp Area averaged 2.89 mm/year before thinning and 3.52 mm/year after thinning, a radial growth increase of 17.8% which was significant at a p=0.07 level (Table 5.2).

Table 5.2. PAI 5-7 years before thinning and 5 years after thinning for trees in the Deer Camp Area.

PAI Before Thinning			PAI After Thinning			Statistics	
N	Mean	Std. Dev.	N	Mean	Std. Dev.	t-value	p-level
107	2.89	0.97	172	3.52	1.12	-1.44	0.07

The 17.9% growth response of trees in the Deer Camp Area was less than the 20% increase reported by Basset (1964) in 30 year old loblolly pine, but substantially higher than the growth response in the Demonstration Area (7.2%). Observations during data collection lead to the conclusion that the higher growth response in the Deer Camp Area may have resulted from better stand stocking, which allowed the contractor to leave more high-quality, co-dominant and dominant trees.

Comparison of Thinning Response Based on Distance to the Skidding Corridor

Two-sample t-tests were again used to test the growth response of trees 0-12 feet from the corridor and trees in areas > 12 feet from rut. The trees 0-12 feet from the corridor were 0.5 inches larger in diameter ($p=0.11$) than the trees growing in the > 12' areas (Refer to Appendix E Table1 for complete results). Total tree height followed the same general pattern: trees growing 0-12 feet from the corridor were 1.0% taller than the trees growing in the > 12' areas ($p=0.27$). The height to the base of the live crown of the trees growing 0-12 feet from the corridor (40.1 feet) was significantly higher ($p=0.10$) than that of the trees growing in the > 12' areas (39.0 feet).

Comparison of radial growth revealed that trees growing more than 12 feet from a corridor grew slightly faster than the trees growing 0-12 feet from the corridor, but the difference was not statistically significant at a $p=0.10$ level (Appendix E Table 1). After thinning, however, the trees growing 0-12 feet from the corridor outpaced those growing in the > 12' areas, but only the fifth year after thinning was significantly different ($p=0.08$).

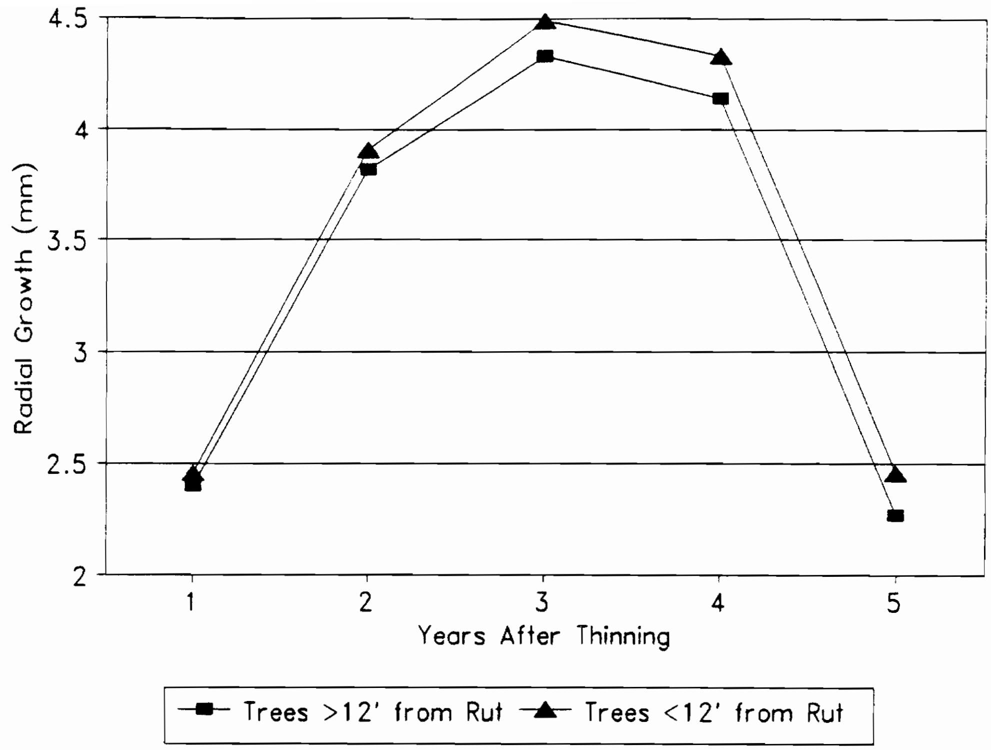

Figure 5.11. Annual radial growth after thinning for trees in the > 12' and 0-12' areas of the Deer Camp Area.

Unlike the Demonstration area, no age differences were found between the trees growing more than 12 feet from the corridor and those within 12 feet of the corridor. A comparison revealed that the PAI of trees growing 0-12 feet from the corridor was 21.5% higher than the PAI of the trees growing in the > 12' areas ($p < 0.01$). The trees growing 0-12 feet from the corridor were thinned more heavily, leaving more open crown space for the crop trees to occupy (Figure 5.10). The PAI's of the trees 0-12 feet from the corridor also may have been elevated above those of the trees in the > 12' areas because they were larger (i.e. dominant and co-dominant) and more vigorous, enabling them to grow faster after thinning.

Comparison of Growth on >12' versus 0-6' areas

Because the first phase of the analysis did not distinguish the growth effects by soil disturbance category, tree data from the areas within 12 feet of the corridor were divided into two groups: trees growing in 0-6' areas (0-6 feet from the corridor) and trees growing in 6-12' areas (6-12 feet from the rut). As stated earlier, the hypothesis being tested was that tree growth closest to the corridor equaled the growth of trees farther from the corridor.

To evaluate the impact on growth, the average PAI for 5-7 years before thinning and the average PAI for the 5 years after thinning were compared for each data class (0-6' areas, 6-12' areas, and >12' areas). All categories showed significant positive growth responses after thinning (Figure 5.12). The trees growing in the >12' areas increased their growth 11.7% after thinning, significant at a $p=0.03$ level. The trees within 6 feet of the corridor had the highest response, a 23.9% increase in radial growth after thinning ($p=0.01$), while the trees located between 6 and 12 feet from the corridor increased their growth 17.3% ($p=0.03$).

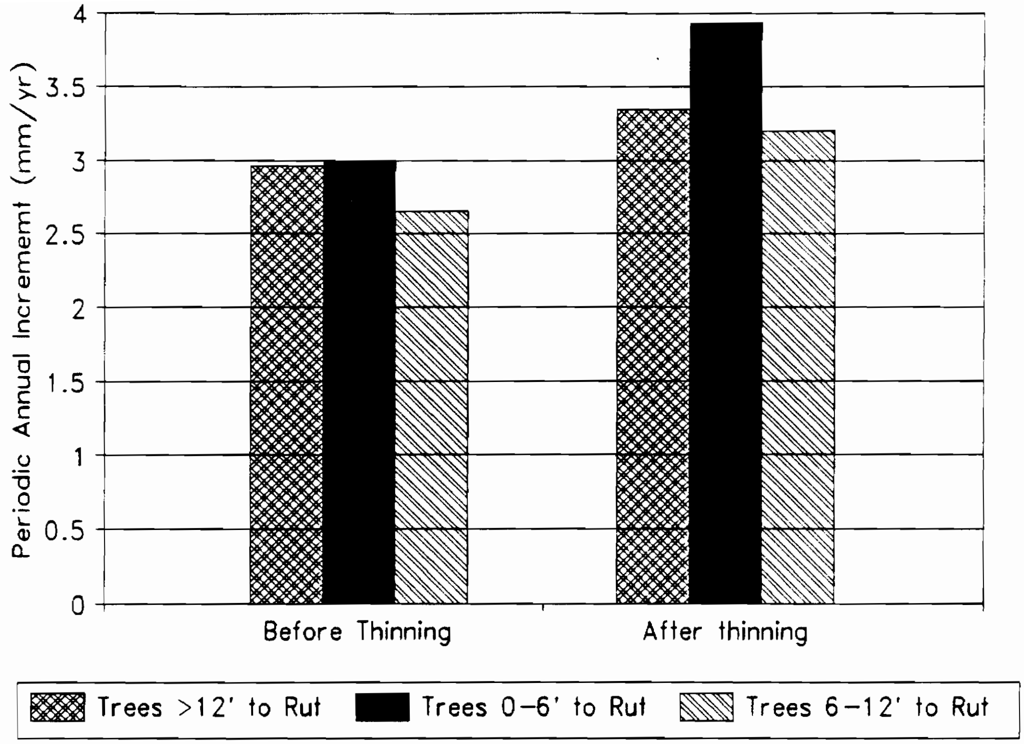

Figure 5.12. Comparison of PAI 5-7 years before thinning and 5 years after thinning for the trees growing in the >12' (from corridor) areas, 0-6' areas, and 6-12' areas of the Deer Camp Area.

Most of the soil compaction observed in the Deer Camp Area was below levels typically thought to reduce tree growth. The bulk density of the skid trails ranged from 0.92-1.25 Mg/m^3 (Chapter 4). Apparently, the minimal soil compaction was offset by the trees' ability to utilize increased crown and root space after mechanized thinning. Other studies have found similar trends; for example, Nickolich (1983) found no negative impacts on loblolly pine in Mississippi one year after thinning on wet soils which were rutted on 91% of the trafficked area. Likewise, Moehring and Rawls (1970) found that after wet weather intermediate harvesting in mature loblolly pine, growth was not reduced unless the soils were heavily trafficked on 3 or 4 sides of the tree.

The comparisons of other tree parameters between the 0-6' and the >12' areas showed the same trends as the general comparisons of the trees 0-12 feet from the corridor versus >12' areas in the Deer Camp Area. The average tree age in 0-6' areas and the >12' areas was not statistically different at $p=0.10$. The trees growing in 0-6' areas had an average DBH of 10.2 inches, while those in the >12' areas averaged only 9.06 inches ($p=0.01$) (Detailed results can be found in Appendix F Table 2). The total height of trees in 0-6' areas was 1.4 feet taller than those growing in the >12' areas ($p=0.39$). The height to the base of the live crown of the trees growing in 0-6' areas was approximately 1.0% higher than that of the trees growing in the >12' areas ($p=0.12$) (Appendix E Table 2).

The radial growth of trees in 0-6' areas was greater before and after thinning than that of the trees growing in the >12' areas. Although the growth differences before thinning were not statistically significant at a $p=0.10$ level, the difference in total radial growth after thinning was significantly different at a $p=0.03$ level. The growth for the two years immediately after thinning was significantly different at a $p=0.12$ level. The third year after thinning, the trees growing in 0-6' areas outgrew the trees growing in the >12' areas by 0.40 mm, significant at the $p=0.06$ level. The fourth year after thinning, the radial growth of the trees growing in 0-6' areas was significantly higher than that of the trees in the >12' areas at a $p= 0.11$ level. The largest significant difference ($p=0.02$) in radial growth occurred the fifth year after thinning, when the trees growing in 0-6' areas grew 0.30 mm more than the trees growing in the >12' areas.

Comparison of Tree Growth in >12' versus 6-12' Areas

Before thinning, the PAI of the trees growing in the >12' areas was 0.32 mm greater ($p=0.11$) than the PAI of the trees in 6-12' areas. After thinning, however, the PAI of the trees growing in the >12' areas was 0.14 mm greater than the PAI of the trees in 6-12' areas ($p=0.20$) (Figure 5.12).

In terms of basic parameters such as DBH and total height, the trees in the 6-12' areas was not statistically different ($p=0.10$) from those in the >12' areas. DBH in the >12' areas were slightly larger (9.06 inches) than in 6-12' areas (8.75 inches) (Appendix E Table 3). The average height of the trees growing in the >12' areas was 0.6 feet taller than those in 6-12' areas ($p=0.37$). Crown width was the only significantly different parameter tested ($p=0.08$); the crowns of the trees growing more than 12' from the corridor were two feet wider than those of the trees growing in 6-12' areas. The total radial growth of the trees in the two disturbance classes was not statistically different before or after thinning.

As in the Demonstration Area, observation during data collection indicated that the areas between the corridors were not as well-thinned as the areas immediately adjacent to the corridors. Therefore, the trees greater than 12 feet from the corridor and those in 6-12' areas did not have adequate room to grow at higher rates. The trees growing in the >12' areas grew faster than the trees in 6-12' areas, suggesting that in addition to the stress of crown closure, soil disturbance may have affected loblolly pine growth in the 6-12' areas after thinning.

The complete discussion of the non-parametric statistical tests can be found in Appendix F, and the comparison of tree parameters based on diameter class and crown class can be found in Appendix G.

Comparison of Tree Growth by Depth of Rut

The data for trees growing in the disturbed areas were sub-divided to determine if growth was affected by the depth of the rut. As in the Demonstration Area, the trees were separated into the following three rut depth categories: 0-3 inches, 3-6 inches, and greater than 6 inches deep.

Comparison of Radial Growth by Depth of Rut

As stated earlier, the overall comparison of PAI 5-7 years before thinning and PAI 5 years after thinning indicated that the stand increased its annual radial growth 17.9% after thinning. Likewise, the trees located near ruts 0-3 inches deep responded significantly ($p=0.01$), with average radial growth increasing from 2.8 mm/yr before thinning to 3.65 mm/yr after thinning (23.3%) (Figure 5.13). The trees located on ruts 3-6 inches deep increased radially from 2.81 mm/yr to 3.67 mm/yr, an increase of 28.6% ($p=0.02$). However, the trees located on ruts deeper than 6 inches lost an average of 4.7% in annual radial growth ($p=0.47$), suggesting that these trees were adversely affected. In contrast, the growth rates did not decrease for trees next to shallower ruts probably because they were able to utilize the additional open crown space and offset any negative impacts caused by rutting.

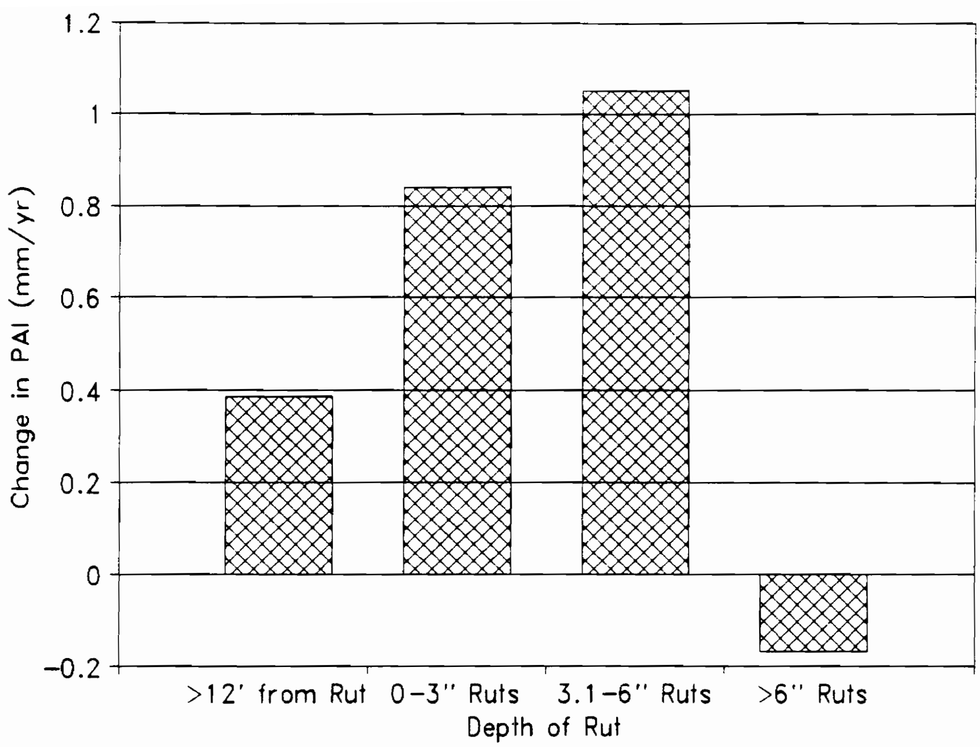

Figure 5.13. Change in PAI after thinning of trees adjacent to ruts 0-3", 3-6", and >6" deep in the Deer Camp Area.

Comparison of Other Tree Parameters Based on Rut Depth

The trees growing next to 0-3 inch ruts were significantly larger in diameter, total height and height to the base of live crown than the trees growing in the zone greater than 12 feet from the corridor. (Appendix H contains the means, standard deviations, and statistical results for these comparisons). No significant differences existed when the total radial growth to the time of thinning was compared. The first four years after thinning, the trees on 0-3 inches deep ruts grew faster than those growing in the >12' areas, but the differences were not significant at a $p=0.10$ level. The fifth year after thinning, however, the trees on ruts 0-3 inches deep grew 8.1%

faster (p=0.08) than the trees growing more than 12 feet from the corridor. After thinning, the total radial growth of the trees on 0-3 inch ruts was significantly larger (p=0.10) than the growth of the trees in the >12' areas. The age of the trees growing more than 12 feet from the corridor was not statistically different (p=0.10) from the age of the trees growing near ruts less than 3 inches deep.

The results of the comparison of trees growing in the >12' areas to those on ruts 3-6 inches deep differed from the trends found in the previous comparison, but the sample size was extremely small (N=7). The DBH of the trees on 3-6 inch ruts was significantly larger (p=0.04) than the DBH of trees growing in the >12' areas (Table 5.3). However, the total height of the trees growing more than 12 feet from the corridor was two feet taller than the trees on 3-6 inch deep ruts (p=0.15).

Table 5.3. Measured parameters of trees growing in the >12' areas and trees adjacent to ruts 3-6" deep in the Deer Camp Area.

	>12' From Corridors			0-12' Areas with 3-6" Ruts			Statistics	
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	t-value	p-level
DBH(in.)	92	9.06	3.44	7	10.51	1.70	-1.98	0.0357
Total height (ft)	68	68.74	8.27	7	66.71	4.27	1.06	0.1535
Crown Width (ft)	68	17.16	6.35	7	14.14	3.08	2.16	0.0241
Growth 1-5 (mm)	65	13.64	6.49	6	11.41	3.61	1.33	0.1064
Growth 6-10 (mm)	65	23.70	9.83	6	28.24	6.71	-1.51	0.0843
Growth 11-15 (mm)	65	25.43	8.99	6	28.71	4.92	-1.42	0.9077
Growth 16-20 (mm)	64	19.92	9	6	18.48	5.15	0.61	0.2801
Growth 21-25 (mm)	46	19.12	16.06	6	14.02	4.36	1.45	0.0902
Growth 26-30 (mm)	10	16.80	6.39	1	13.62	-	-	-

For the first five years after stand origination, the trees growing in the $>12'$ areas grew faster than the trees growing in areas with 3-6 inch ruts. For the next ten years, the trees growing near the ruts grew significantly faster ($p=0.10$) than the trees growing in the $>12'$ areas. During the 16-25 year period, the trees growing more than 12' from the corridor again grew faster than the trees growing near 3-6 inch ruts; this difference was significant ($p=0.09$) during the period from 20-25 years of age (Table 5.3). These results may partially result from the significantly wider crowns of the trees growing in the $>12'$ areas (Table 5.3). This increased crown area may allow the trees an advantage in obtaining height growth. However, increased crown size is typically associated with increased diameter growth (Seiler 1991), which did not occur in the trees on the areas more than 12' from the corridor.

After thinning, the trees growing adjacent to ruts 3-6 inches deep grew faster radially than did the trees growing in the $>12'$ areas (Figure 5.14). Nevertheless, the only significant difference occurred the fourth year after thinning, when the trees growing on 3-6 inch ruts grew 14.8% more than the trees growing in the $>12'$ areas ($p=0.08$).

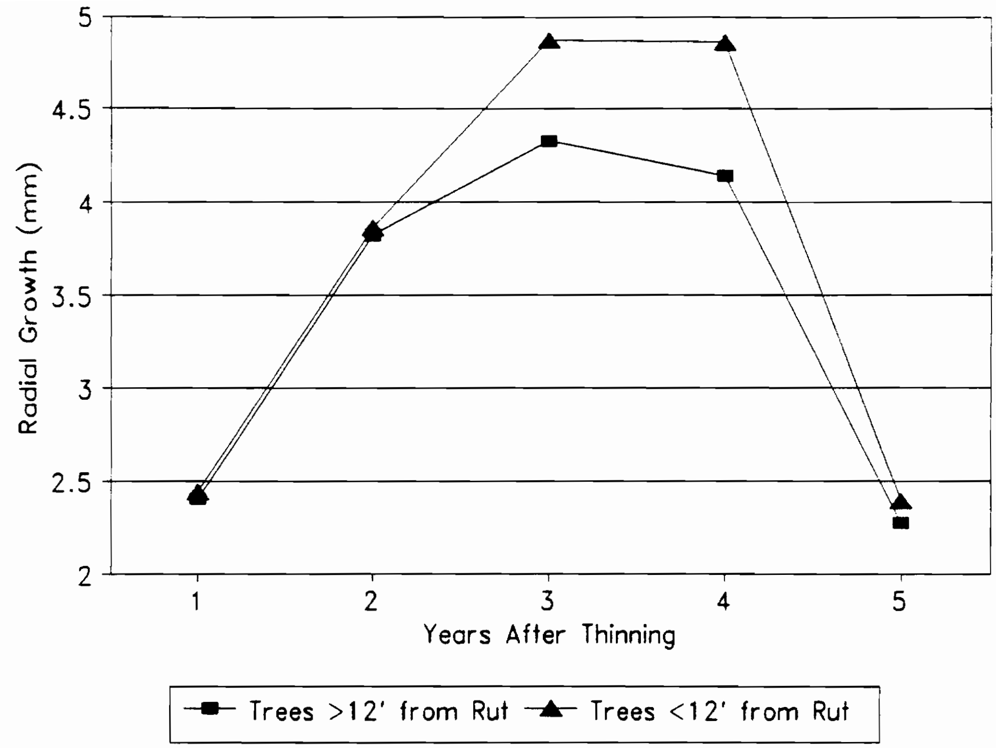

Figure 5.14. Growth after thinning of trees in the > 12' areas and trees growing adjacent to ruts 3-6" deep in the Deer Camp Area.

The trees next to ruts 3-6 inches deep evidently were not affected by rutting and responded 8.9% faster than the trees growing in the > 12' areas five years after thinning (p=0.11). Based on these results, ruts less than 6 inches deep did not appear to negatively affect the growth of loblolly pine in the Deer Camp Area.

Surprisingly, the comparison of the trees growing in the > 12' areas with the trees located on ruts greater than 6 inches deep yielded even fewer significant differences. Sample size (N=8) was again rather small for the disturbed areas. The trees adjacent to ruts greater than 6 inches deep had a larger average diameter (10.76 inches) than the trees growing more than 12' from the corridor (9.06 inches) (Appendix H Table 3), significant at the p=0.10 level. At a p-level of 0.10, there were no significant differences in total height or crown width. Before thinning, radial growth for trees near ruts deeper than 6 inches was higher than that of trees growing in the > 12' areas. This difference was significant during the period 6-15 years after stand origination (p=0.06). After thinning, the radial growth of the trees on deep ruts did not differ significantly from the radial growth of the trees growing in the > 12' areas at a p=0.10 level (Figure 5.15). After thinning, both groups grew at approximately equal rates. The trees growing in the > 12' areas were one year older than those growing on ruts deeper than 6 inches, significantly different at a p=0.03 level.

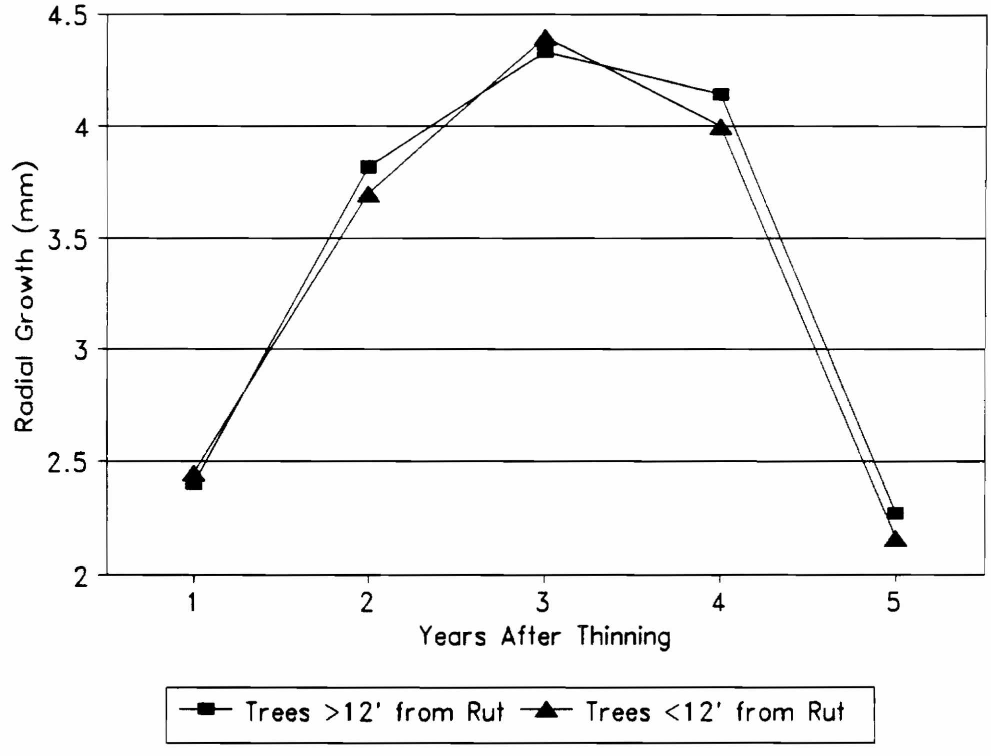

Figure 5.15. Growth after thinning of trees more than 12' from the corridor and trees located on ruts deeper than 6" in the Deer Camp Area.

The trees near the deepest ruts did not outgrow the trees growing in the > 12' areas, indicating that machine traffic can reduce the vigor and growth of trees when ruts are deeper than 6 inches. The trees on the deepest ruts grew much faster from stand origination to the time of thinning, but did not maintain this growth advantage after thinning.

Summary

Based on distance from the rut, the trees growing in 0-6' areas responded much better to thinning than the trees growing in the > 12' areas. During thinning, more small trees were removed from the area 0-12 feet from the corridors as the diameter distribution of trees in this area revealed (Appendix F, Figure F.1). The diameter distribution of trees in the > 12' areas contained even fewer large trees. Therefore, the trees growing in the > 12' areas were smaller than the trees growing in 0-6' areas and smaller or equal in size to the trees growing in 6-12' areas. Apparently the contractor removed the trees in the > 12' areas that were easiest to reach or had the highest value, thereby effectively removing the trees that would have responded best to the thinning.

CHAPTER 6

RESULTS AND DISCUSSION -- DAMAGED TREES

In even the most careful thinning operations, harvesting equipment may damage some of the residual trees by scraping off bark, creating basal wounds which are potential entry points for infections. To determine if such bole damage decreased the growth of loblolly pine on the two Arkansas study sites, tests were conducted on trees that were physically damaged during thinning. These trees were not included in any previous tests to avoid confusing the effects of soil disturbance with the effects of actual physical damage to the trees. The trees on each study area were separated into three categories based on the distance from the corridor. (Other methods of grouping the data were not used because they yielded very small sample sizes.) As in the previous analyses, these categories were 0-6 feet from the rut, 6-12 feet from the rut, and > 12 feet from the rut. Two-sample t-tests (using the Welch approximation) were conducted to compare the undamaged trees and the damaged trees within the data groups.

DEMONSTRATION AREA

The same procedure outlined in Chapter 5 was used to test various attributes of the damaged trees against those of the undamaged trees in the Demonstration Area. The actual sizes of bark wounds were not measured, but estimated and grouped into small, medium, and large categories. The damaged trees had bole wounds ranging from three to 40 square inches. There were 40 damaged trees in the Demonstration

Area, 11.7% of the entire residual stand. Because of small sample size, all damaged trees were analyzed as one group.

Comparison of Undamaged versus Damaged Trees in Areas Greater Than 12 Feet from the Corridor

The areas >12' from the corridor contained only 10 damaged trees, 8.4% of the total undisturbed area sample. The average DBH of the undamaged trees was 7.4 inches, whereas the average DBH of the damaged trees was 8.6 inches (Appendix I). These diameters were not significantly different at a $p=0.10$ level, probably because the trees varied widely in diameter and the sample size was very small ($N=10$). The damaged trees were 5.2 feet taller than the undamaged trees, a difference not significant at the $p=0.10$ level. The undamaged trees had an average height to the base of the live crown of 34.0 feet, 0.6 feet taller than that of the damaged trees (33.4 feet), but this height difference was not significant at a p-level of 0.10. The crown widths of the damaged trees were an average of five feet wider than those of the undamaged trees, significant at a $p=0.03$ level.

Growth before thinning was also greater for the damaged trees than for the undamaged ones. The damaged trees grew significantly faster ($p=0.10$) the first fifteen years after stand establishment (Appendix I). Although the damaged trees grew faster than the undamaged trees from year 16 to the time of thinning, the differences were not statistically significant at a $p=0.10$ level. On average, the damaged trees grew 22.9% faster before thinning than the undamaged trees, but this growth discrepancy was not statistically significant at a $p=0.10$ level. Because the damaged trees grew faster before thinning, their total growth from the pith to the time of thinning was significantly larger ($p=0.03$) than that of the undamaged trees.

The damaged trees continued to outgrow their undamaged counterparts after thinning. The first year after thinning, the damaged trees grew 3.76 mm radially, whereas the undamaged trees grew only 2.80 mm, a difference significant at a $p=0.10$ level (Appendix I). The second year after thinning, the damaged trees increased their growth to 5.17 mm, while the undamaged trees grew only 3.50 mm, a 32.3% difference significant at a $p=0.02$ level. The third year after thinning, the growth of both damaged and undamaged trees decreased, but the damaged trees grew significantly faster ($p=0.01$) than the undamaged trees. The fourth year after thinning, the damaged trees grew an average of 25% faster than the undamaged trees, significant at a $p=0.03$ level.

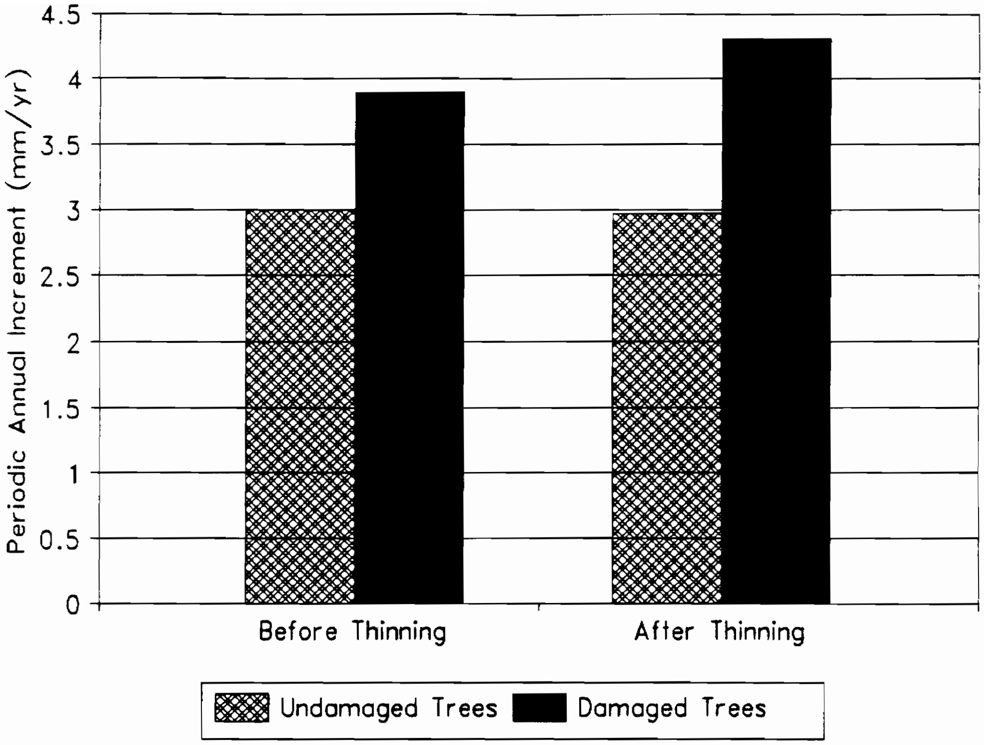

Figure 6.1. PAI before and after thinning for the undamaged and damaged trees in the > 12' areas of the Demonstration Area.

The damaged trees had a greater total height and a lower height to the base of the live crown, signifying that these trees had a larger crown ratio than the undamaged trees. Such an advantage in crown size could explain their growth advantage after thinning. Because the damaged trees had larger crowns and were taller, they benefited from decreased competition. After thinning the damaged trees continued to grow well, increasing their average annual growth from 3.89 mm to 4.29 mm, a 9% increase. However, this increase in growth was not statistically significant at a $p=0.10$ level. The undamaged trees actually decreased their average annual growth slightly after thinning, but the difference was not significant at a p-level of 0.10. Because the undamaged trees were not adequately thinned, crown size did not increase which could have led to faster growth. In contrast, the damaged trees were partially released, and responded to the increased crown space by increasing their growth. However, the 9% increase was not statistically significant, leading to the conclusion that basal damage reduced the potential growth response of the damaged trees. Zobel and Talbert (1984) stated that partial girdling of the stem often results in increased flower and cone crops. Such a response is unwanted in a commercial thinning, because reproductive growth is unusable biomass which does not increase the diameter and value of the crop trees at final harvest.

Comparison of Undamaged versus Damaged Trees in Areas 0-6' from the Corridor

Most of the damaged trees (N=19) were located within 6 feet of the corridor and represented almost 20% of the trees growing in these areas. The damaged trees had a slightly larger average DBH than did the undamaged trees ($p=0.24$) (Appendix I). The damaged trees were only 0.7 feet shorter than the undamaged trees ($p=0.42$) and the crown widths of the damaged trees were 3 feet narrower than those of the undamaged trees ($p=0.02$).

For the first five years after stand establishment, the total radial growth of the damaged trees (18.7 mm) was statistically greater ($p=0.06$) than the radial growth of the undamaged trees (14.3 mm) (Appendix I). However, by the eleventh year of growth, the undamaged trees were growing faster than the damaged trees, a trend that continued through the twenty-fifth year of growth. The average annual growth (PAI) for 5-7 years before thinning was approximately the same for the undamaged trees (2.85 mm) and the damaged trees (2.89 mm) (Figure 6.2).

After thinning, the undamaged trees grew faster than the damaged trees, but not at significantly different ($p=0.10$) rates (Appendix I). The undamaged trees responded to thinning by increasing their growth to an average of 3.28 mm per year, but the damaged trees averaged only 2.91 mm per year after thinning (Figure 6.2). These growth rates represent a 13.1% increase for the undamaged trees, but only a 0.7% increase for the damaged trees (Figure 6.2).

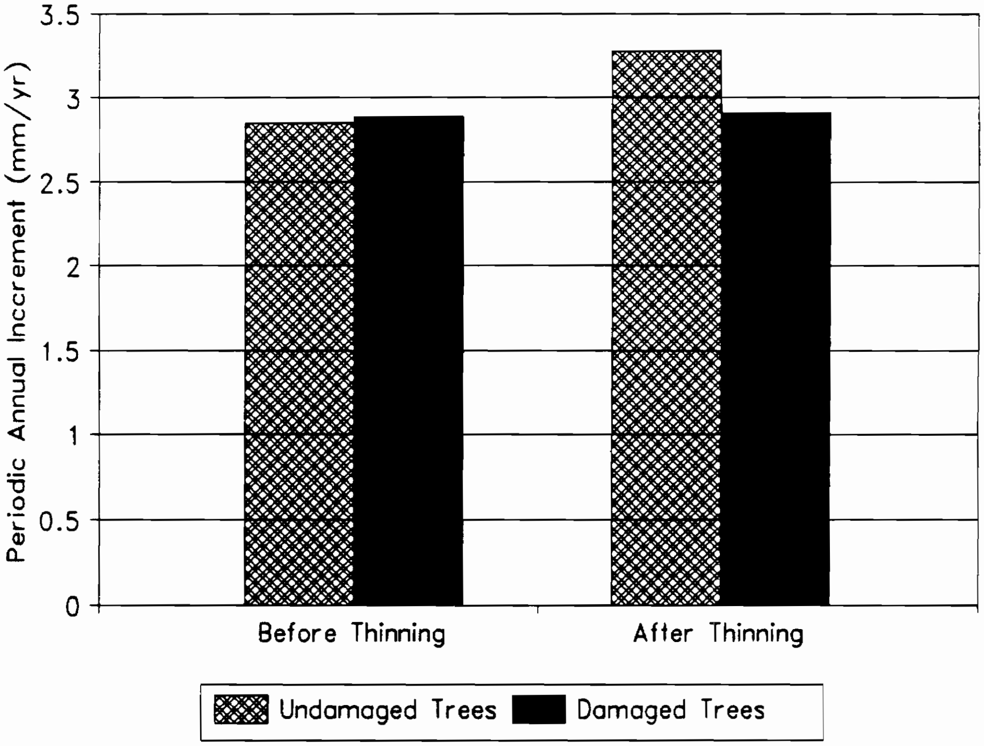

Figure 6.2. PAI before and after thinning for the undamaged and damaged trees growing in the 0-6' areas of the Demonstration Area.

Analysis of the data indicated that the damaged trees growing within 6 feet of the corridor did not respond favorably to the thinning operation. The impacts of physical and soil damage probably combined to produce the poor growth response of the trees in the 0-6' areas.

Comparison of Undamaged versus Damaged Trees in Areas 6-12 Feet From The Corridor

In the 6-12' areas of the Demonstration Area, the 11 damaged trees were significantly larger than the undamaged trees ($p=0.05$) (Appendix I). The total height of the damaged trees was approximately four feet taller than the undamaged trees ($p=0.21$). Part of this large size difference resulted from the faster growth of the damaged trees before thinning. The growth of the damaged trees and undamaged trees were similar until 16-20 years after stand origination, at which time the periodic increment of the damaged trees was significantly larger than that of the undamaged trees at a $p=0.01$ level. The radial growth increment of the damaged trees for the next five year period was significantly larger ($p=0.03$) than the increment for the undamaged trees. During the 5-7 year period immediately before thinning, however, both the undamaged and damaged trees grew at similar rates; the undamaged trees grew 2.73 mm per year and the damaged trees grew 3.04 mm per year ($p=0.27$).

After thinning, the damaged trees grew faster than the undamaged trees each year, but the differences were statistically significant ($p=0.05$) only in the first year after thinning (Appendix I). The average annual radial growth of damaged trees increased 21.7% after thinning, to 3.89 mm per year (Figure 6.3). The undamaged trees grew an average of 3.05 mm per year after thinning, an increase of only 10.5% after the thinning operation. This growth difference between damaged and undamaged trees was significant at the $p=0.11$ level.

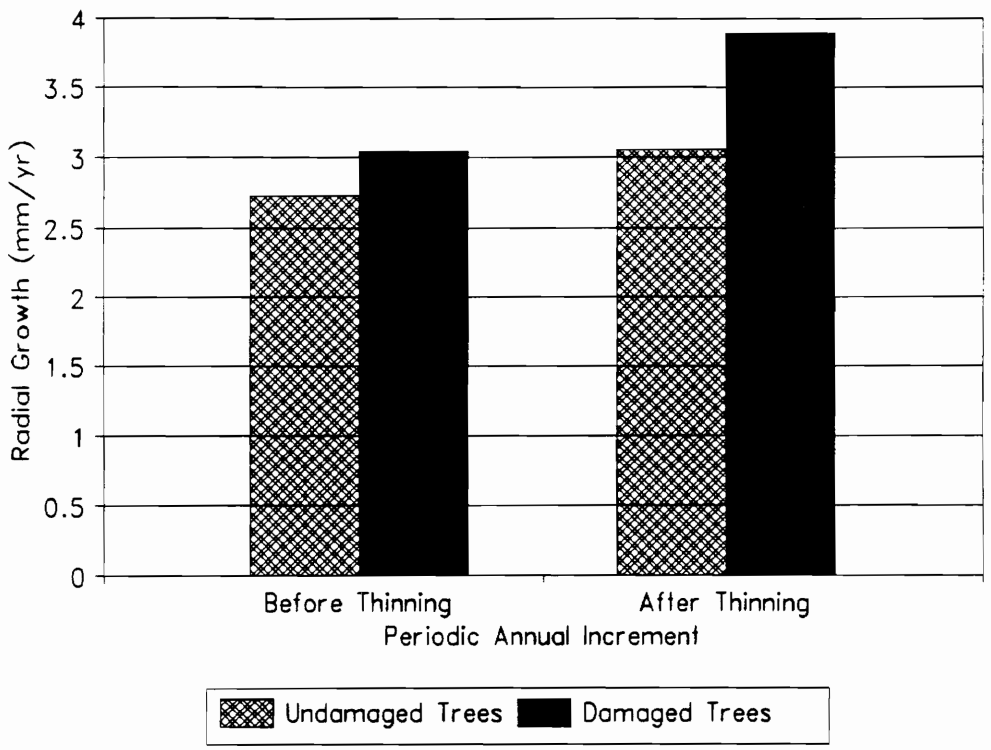

Figure 6.3. PAI before and after thinning for the undamaged and damaged trees in the 6-12' areas of the Demonstration Area.

Because the damaged trees grew faster than the undamaged trees in the 6-12' areas, the situation was probably similar to that in the > 12' areas. The trees that were damaged were better released than the undamaged trees, and the basal wounds did not seem to affect tree growth or vigor.

DEER CAMP AREA

The testing procedures used for the Deer Camp Area paralleled those used for evaluating growth in the Demonstration Area. Overall, 7.8% of the residual trees in the Deer Camp Area were damaged (i.e. N=27) by harvesting equipment during the thinning operation. The basal wounds occurring in the Deer Camp Area were very similar to the wounds found in the Demonstration Area. Wound size ranged from approximately 3 to 40 square inches.

Comparison of Undamaged versus Damaged Trees in Areas Greater Than 12 Feet From The Corridor

The DBH (11.35 inches) of damaged trees in the >12' areas were significantly larger ($p=0.10$) than the undamaged trees (9.05 inches) (Appendix J). The total height of the undamaged trees was 2.2 feet higher than the total height of the damaged trees, but this difference was not significant at a $p=0.10$ level. The height to the base of the live crown was 7.6% higher for the undamaged trees than for the damaged trees, significantly different at the $p=0.07$ level. Before thinning, the growth of the trees in the two disturbance classes was not significantly different at a $p=0.10$ level. However, the damaged trees had slightly higher growth rates than did the undamaged trees for all but the first five years of growth after stand origination. During this period, the undamaged trees outgrew the damaged trees by 13.5%. From year five until the time of thinning, the damaged trees outgrew the undamaged trees by approximately 9.9%. After thinning, the radial growth response of the damaged trees was slightly higher than that of the undamaged trees, but the difference was insignificant at the $p=0.10$ level.

To determine the growth response after thinning, the PAI for the 5-7 years before thinning was compared to the PAI after thinning. The damaged trees had an average PAI of 3.07 mm per year before thinning and 3.55 mm per year after thinning (Appendix J). Because the sample size was small (N=4), this 13.5% growth increase was not significant at the $p=0.10$ level. By comparison, the undamaged trees grew an average of 2.96 mm per year for the 5-7 years before thinning and 3.34 mm per year after thinning, an 11.1% increase that was statistically significant at the $p=0.03$ level.

The removal of trees adjacent to the damaged trees increased the available crown space, allowing the damaged trees to increase radial growth and to overcome the shock of physical damage to the bole. If the undamaged trees had been adequately thinned, they might have outgrown the damaged trees. Even though the trees in this study were unaffected by mechanical damage, care should be taken to avoid tree damage during thinning, because such damage sometimes affects tree survival. Wounds are infection courts where organisms can enter, causing the tree to develop heart rot or other fatal diseases (Nebeker and Hodges 1985). Also, basal damage reduces the value of the butt log, typically the most valuable log of the tree.

Comparison of Undamaged versus Damaged Trees in Areas 0-6 Feet From The Corridor

The growth trends for damaged and undamaged trees in the 0-6 feet zone from the corridor were very similar to the >12' zone, even though these areas contained the majority of the mechanically damaged trees (N=20). The average DBH (12.13 inches) of the damaged trees was significantly larger ($p=0.01$) than the DBH of the undamaged trees (10.6 inches). Both total height and height to the base of the live crown were larger for the damaged trees (Appendix J). The damaged trees were 2 feet taller (significant at the p=0.06 level) and the height to the base of the live crown was also significantly higher (p=0.04). Before thinning, these trees had similar growth rates, although the damaged trees grew slightly faster than the undamaged trees particularly during the 11-15 year period after stand origination (p=0.04). In addition, the average PAI before thinning of the damaged trees was significantly higher (p=0.10) than that of the undamaged trees (Figure 6.4).

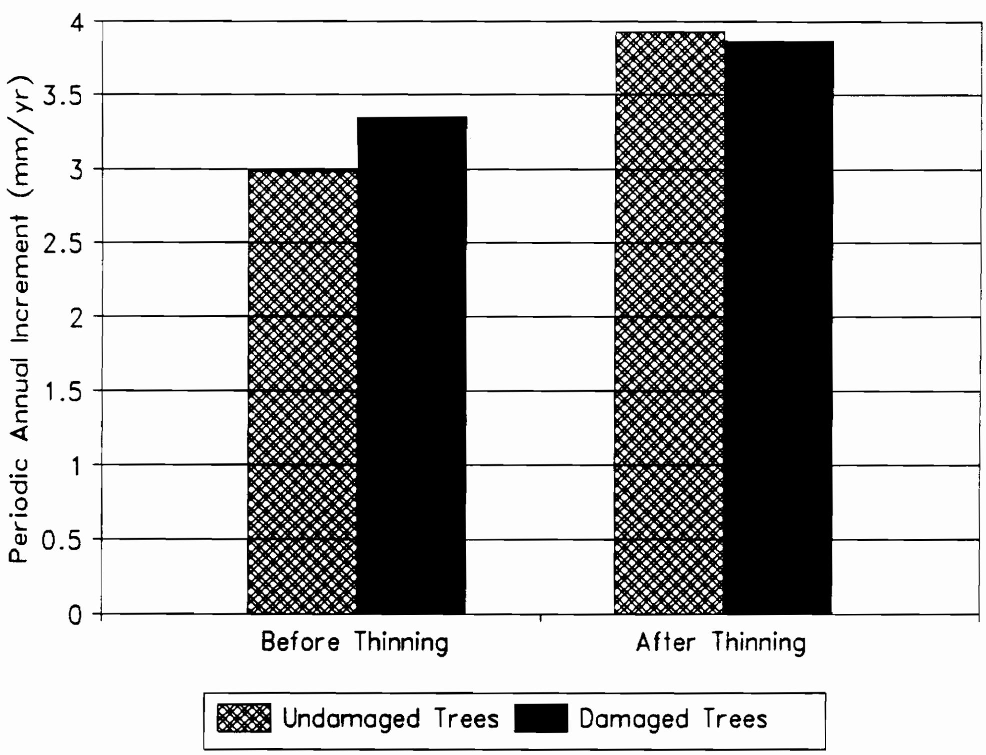

Figure 6.4. PAI before and after thinning for the damaged and undamaged trees in the 0-6' areas of the Deer Camp Area.

After thinning, the damaged and undamaged trees in the 0-6' areas did not have different radial growth responses (Figure 6.4). The damaged trees responded to thinning by increasing their annual radial growth 12.0%, an increase significant at a p=0.10 level. The undamaged trees, however, responded faster by increasing growth 23.9% (0.9 mm) after thinning. As in the Demonstration Area, the damaged trees growing in the 0-6' areas failed to match the response of the undamaged trees, and growth declined when the stress of physical damage was coupled soil disturbance next to the corridor.

Comparison of Undamaged versus Damaged Trees in Areas 6-12 Feet From The Corridor

The diameters of the 3 damaged trees in the 6-12' areas were 5 inches larger than those of undamaged trees, significant at the p=0.03 level (Appendix J). The height of the damaged trees was also 8 feet taller than the undamaged trees, significant at the p=0.07 level. The three trees that were damaged were the largest trees in the 6-12' areas, and probably were damaged because the thinning operator sought to release these trees. However, it is possible that these trees had already attained dominance in the stand prior to thinning.

The damaged trees grew at a much faster rate before thinning than did the undamaged trees. The PAI before thinning was 2.64 mm per year for the undamaged trees and 3.29 mm per year for the damaged trees not significant at a p=0.10 level (Appendix J). The PAI after thinning for the undamaged trees was only 3.20 mm per year, compared to 4.03 mm per year for the undamaged trees. The damaged trees increased their annual radial growth by 0.74 mm (18.4%), which was not statistically different from their growth before thinning ($p=0.10$) (Figure 6.5). The undamaged trees increased their annual radial growth by 0.55 mm (17.2%), an increase significant at the $p=0.03$ level (Figure 6.5).

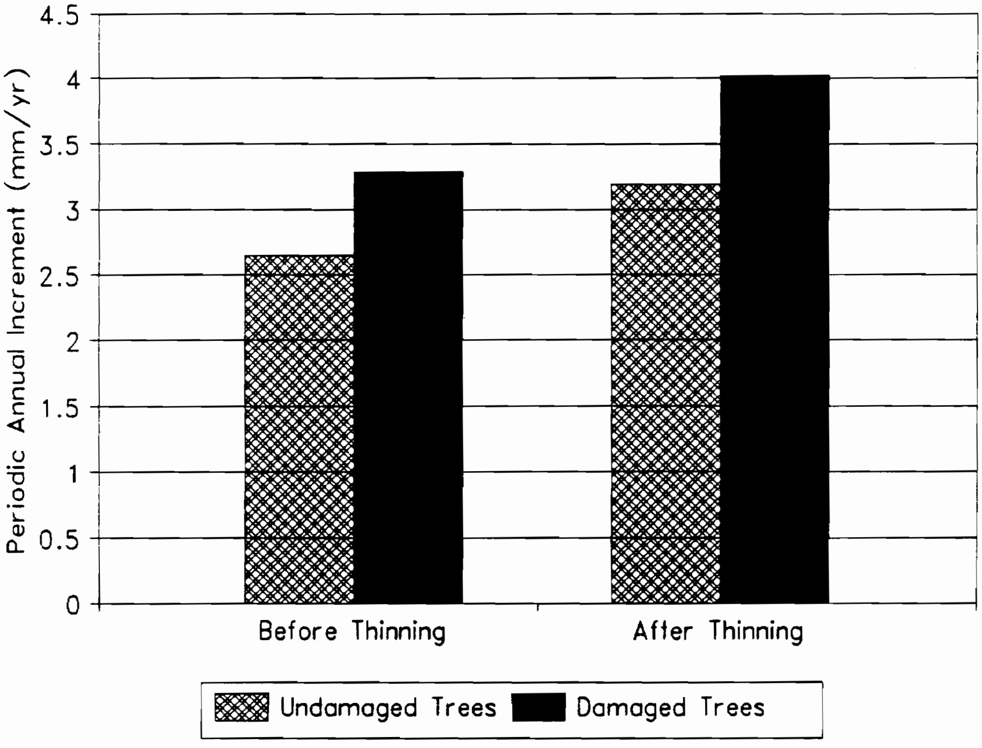

Figure 6.5. PAI before and after thinning for the undamaged and damaged trees in the 6-12' areas of the Deer Camp Area.

In the 6-12' areas, the damaged trees did not appear to be negatively impacted by their injuries, and outgrew the undamaged trees by 21% after thinning. This growth response supports the observation that the damaged trees were more adequately released than the undamaged trees. The additional crown space, water, and nutrients present after thinning favored the growth of the damaged trees despite their basal wounds.

SUMMARY

Based on this analysis, the damaged trees located closest to the rut grew slower after thinning than did the damaged trees farther from the rut. In the Deer Camp Area, damaged trees 6-12 feet from the rut increased their growth the most (18.4%). In contrast, the damaged trees in the >12' areas increased their growth by 13.4%, while those in the 0-6' areas increased their growth by only 12.0%.

The damaged trees growing in soils more than 12 feet from the corridor generally did not respond well to the thinning treatment. These trees were located in the areas that were thinned lightly; however, several trees in these areas were damaged, suggesting that trees in the immediate area were removed. Apparently, the small basal scars did not impede tree growth unless the tree was otherwise stressed. The trees in the 6-12' areas were thinned more heavily than the trees growing more than 12 feet from the corridor, but not as heavily as the trees immediately adjacent to the corridor. For the trees in the 6-12' areas, the minor soil disturbance and extra crown space after thinning benefited growth more than the negative impact of basal damage. The damaged trees closest to the rut had the largest potential crown space after thinning, but the combined effects of soil disturbance and basal wounds apparently reduced tree growth.

The damaged trees were mostly dominant and co-dominant trees, whereas the undamaged trees were dominant, co-dominant, and intermediate trees. The growth of the damaged and undamaged trees before thinning was very similar, with the damaged trees beginning to grow slightly faster after five years of growth. Even though growth before thinning was statistically greater ($p=0.06$) for the damaged trees than for the undamaged trees, the damaged and undamaged trees grew at approximately the same rate after thinning.

These results clearly indicate that the combined stresses of physical damage and soil disturbance decrease loblolly pine's ability to respond favorably to thinning. Because the damaged trees did respond to thinning with a 12.0% growth increase, the physical damage to these trees apparently was not excessive. However, such bole damage should be avoided whenever harvesting machines are operating in thinned stands.

CHAPTER 7

SUMMARY AND CONCLUSIONS

This research project was undertaken to determine the effects of mechanized harvesting equipment on the soil physical properties and residual tree growth in two natural loblolly pine stands in Grant County, Arkansas. The study consisted of post-harvest evaluation of the 1.9-acre Demonstration Area and the 4.0-acre Deer Camp Area, which were thinned 4 and 5 years before this study, respectively. Both study areas were corridor thinned and the trees between the corridors were selectively removed based on the operator's discretion.

Both the Demonstration and the Deer Camp Areas contained soil and residual stand damages typically incurred during mechanized thinning operations in wet weather. The skid trails in these areas were rutted, but the majority of ruts in both stands were less than 6 inches deep. Some trees in each area had bole wounds from contact with harvesting equipment. Growth of the residual trees was evaluated to determine if the machines used to thin the stand affected loblolly pine growth either directly, by physically damaging trees, or indirectly, by rutting or compacting the soils.

The soil data collected from each study area revealed that the soils were not significantly compacted even though those areas were harvested when soil moisture was high (i.e. winter). Four to five years after thinning, the bulk densities on the skid trails for both sites were below 1.3 Mg/m^3, the point at which loblolly pine root growth is impeded. The soils on both study sites had adequate soil drainage and aeration, as indicated by measurements of saturated hydraulic conductivity and macroporosity. On the skid trails, the microporosities of the soils were slightly elevated, which caused the increases in bulk density. The saturated hydraulic conductivity of the soils in the skidding corridors was lower than the hydraulic conductivity of the undisturbed soils, but probably not low enough to prevent the study areas from draining. Only small portions of both study areas contained ruts deeper than 6 inches. The soils had 4-5 years of wet/dry cycles, and also appeared (based on casual field observation) to be colonized by earthworms and grasses, which tend to ameliorate the soil. Because the soils were not heavily disturbed over most of the stand, loblolly pine growth should not have been adversely affected.

In the Demonstration Area, the diameters of trees in the 0-6 foot areas were significantly larger than those of trees in the > 12 foot areas. In the Deer Camp Area, the diameters of the trees in the 0-6 foot areas were also significantly larger than the diameters of trees in the >12 foot and 6-12 foot areas, suggesting that the thinning contractor failed to remove enough of the co-dominant, intermediate, and suppressed competition from the > 12 foot and 6-12 foot areas. The comparisons of other tree parameters such as total height, height to the base of the live crown, and crown width in the >12 foot, 6-12 foot, and 0-6 foot areas did not provide consistent trends in either study area. The comparison of the tree parameters by diameter class and distance to the nearest rut failed because of small sample sizes.

Comparisons of tree growth based on the depth of the nearest rut indicated several significant trends and differences in both study areas. Growth was negatively affected when machine traffic broke through the soil's coarser A horizon into the finer subsoil to depths greater than 6 inches. On the other hand, trees located on ruts less than 6 inches deep responded extremely well in both the Demonstration and Deer Camp Areas, suggesting that loblolly pine trees can overcome the impacts of slight soil disturbance if they have ample crown space. Another possibility is that the majority of the soils in these stands were not detrimentally impacted by the harvesting equipment. Therefore, the increased machine traffic needed to thin the areas between the corridors should not affect tree growth. Adequate thinning in the areas more than 12 feet from the corridor would help to release these trees, allowing them to grow at rates similar to those of trees growing near the corridors.

The literature suggests that mature loblolly trees which have severe rutting on only one or two sides of the tree do not suffer detrimental impacts. The results from this study indicate that tree growth may be affected if one side of the tree is deeply rutted. However, although significant growth responses were found based on rut depth, the author feels that these results should be used with discretion because of the small sample size of trees on ruts deeper than 6 inches. The trends found in this study indicate that a problem may exist, but additional studies should examine the impact on growth when deep ruts are formed by mechanized thinning equipment.

Several factors could cause the trees on the shallow ruts to grow faster than those located in the > 12' areas. Other research suggests that trees growing on heavily trafficked soils initially lost growth, but began to recover after five years. In this study, the soils on only one side of the trees were trafficked; therefore, most of each tree's root system was not affected and the remaining undamaged root system was able to provide the tree with adequate nutrients, water and other resources. Also, the physiological stress experienced by the trees located near corridors was offset because of decreased competition after thinning. Therefore, tree growth was not affected because the soil was not damaged or the trees were able to recover at a faster rate than suggested in the literature.

The main reason tree growth next to the corridor exceeded that of trees greater than 12 feet from the corridor is that the trees adjacent to skid trails were thinned more heavily. Because these trees did not experience crown closure, they continued to grow at higher rates than the more crowded trees in the > 12 foot areas. The feller-buncher operator selectively removed the smaller trees along the corridors, but did not remove as many small trees in the areas between (> 12 foot) the corridors.

Residual stand damage that occurred during thinning also appeared to have negative effects on tree growth. The radial growth of damaged trees 0-6 feet from the corridor was less after thinning than for damaged trees growing in the > 12 foot areas. The combined effects of physical damage and soil disturbance tend to overwhelm loblolly pine's ability to respond after thinning. Besides reducing radial growth, bole wounds provide entry points for destructive organisms such as heart rot fungi or reduce the vigor of trees, leaving them susceptible to attacks by the southern pine beetle. Methods for controlling bole damage during thinning deserves careful consideration. It can usually be controlled by planning the layout of skid trails, carefully making skidding turns, and by creating corridors wide enough to handle the anticipated levels of skidding traffic.

Because of uneven thinning, corridor rutting, and mechanical damage, the overall adequacy of thinning (i.e. increasing the radial growth of the trees) was only marginally achieved in the two study areas. Based on this study, thinning should be planned during dry weather to minimize soil rutting. If thinning must be done under wet conditions, the operation should stop when machine traffic creates ruts deeper than the soils coarser horizons. If such efforts are not made to minimize soil disturbance and residual stand damage, the potential benefits of thinning may not be fully realized.

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Appendix A

Tables of Tree Parameters for the > 12 foot, 0-6 foot and 6-12 foot Areas of the Demonstration Area.

Table A.1. Summary of all tree parameters tested in the areas >12 feet from the corridor and trees 0-12 feet from the corridor in the Demonstration Area.

	Trees >12' From Corridor			Trees 0-12' From Corridor			Statistics	
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	t-value	p-level
DBH (in.)	109	7.39	3.30	161	7.46	3.57	-0.14	0.4434
Hgt. to Base Live Crown (ft)	74	34.04	7.33	111	33.16	6.99	0.82	0.2075
Total Height (ft)	109	50.37	12.35	159	49.86	13.96	0.32	0.3761
Crown Width (ft)	74	14.97	6.77	111	16.04	6.66	-1.06	0.145
Age (yr)	78	26.49	2.85	106	27.41	2.59	-2.25	0.013
Growth Years 1-5 (mm)	77	13.83	7.78	106	14.23	7.41	-0.35	0.3653
Growth Years 6-10 (mm)	77	22.76	11.16	106	22.89	8.64	-0.01	0.4694
Growth Years 11-15 (mm)	77	19.63	7.38	106	22.54	11.35	-2.10	0.0183
Growth Years 16-20 (mm)	66	17.36	6.78	100	18.75	8.03	-1.20	0.1157
Growth Years 21-25 (mm)	20	15.52	5.18	39	17.69	7.52	-1.30	0.0996
Growth Pith-Thin (mm)	76	79.67	29.18	105	88.87	33.28	-1.97	0.0251
Growth Year Thin + 1 (mm)	76	2.80	1.55	105	2.99	1.50	-0.85	0.1987
Growth Year Thin + 2 (mm)	76	3.50	2.02	105	3.61	1.73	-0.38	0.3529
Growth Year Thin + 3 (mm)	76	3.17	1.74	105	3.60	3.98	-1.79	0.0379
Growth Year Thin + 4 (mm)	76	2.58	1.67	105	2.81	1.38	-0.96	0.1699
Growth Thin-Bark (mm)	75	11.83	5.93	105	13.52	7.20	-1.71	0.0441
Growth Pith-Bark (mm)	75	91.02	34.71	105	102.43	38.89	-2.07	0.0221

Table A.2. Summary of all tree parameters tested in the areas > 12 feet from the corridor and trees 0-6 feet from the corridor in the Demonstration Area.

	Trees >12' From Corridor			Trees 0-6' From Corridor			Statistics	
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	t-value	p-level
DBH (in)	109	7.39	3.30	81	7.41	3.56	-0.00	0.4879
Hgt. to Base Live Crown (ft)	74	34.04	7.33	57	33.52	7.33	0.41	0.3431
Total Height (ft)	109	50.37	12.35	79	50.59	14.44	-0.11	0.4549
Crown Classification *	107	2.78	1.00	82	2.80	0.96	-0.14	0.4452
Crown Width (ft)	74	14.97	6.77	57	16.42	6.67	-1.22	0.1118
Age (yr)	78	26.49	2.85	53	27.55	2.74	-2.14	0.0172
Growth Years 1-5 (mm)	77	13.83	7.78	53	14.34	7.93	-0.36	0.3583
Growth Years 6-10 (mm)	77	22.76	11.16	53	22.86	8.57	-0.01	0.4799
Growth Years 11-15 (mm)	77	19.63	7.38	53	21.84	9.25	-1.46	0.0740
Growth Years 16-20 (mm)	66	17.36	6.78	50	18.81	7.24	-1.10	0.1364
Growth Years 21-25 (mm)	20	15.52	5.18	22	17.46	6.80	-1.04	0.1516
Growth Pith-Thin (mm)	76	79.67	29.18	53	89.16	33.17	-1.68	0.0481
Growth Years Thin + 1 (mm)	76	2.80	1.55	53	3.15	1.31	-1.38	0.0853
Growth Years Thin + 2 (mm)	76	3.50	2.02	53	3.61	1.55	-0.34	0.3683
Growth Years Thin + 3 (mm)	76	3.17	1.74	53	3.53	1.59	-1.22	0.1132
Growth Years Thin + 4 (mm)	76	2.58	1.67	53	2.85	1.25	-1.04	0.1509
Growth Thin-Bark (mm)	75	11.83	5.93	53	13.32	4.96	-1.54	0.0636
Growth Pith-Bark (mm)	75	91.02	34.71	53	103.33	39.44	-1.83	0.0353

* Crowns are classified from 1 (dominant trees) to 4 (suppressed trees).

Table A.3. Summary of tree parameters tested in the areas > 12 feet from the corridor and trees 6-12 feet from the corridor in the Demonstration Area.

	Trees >12' From Corridor			Trees 6-12' From Corridor			Statistics	
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	t-value	p-level
DBH (in)	109	7.39	3.30	80	7.50	3.58	-0.21	0.4182
Hgt. to Base Live Crown (ft)	74	34.04	7.33	54	32.78	6.68	1.01	0.1564
Total Height (ft)	109	50.37	12.35	80	49.12	13.52	0.65	0.2592
Crown Classification *	107	2.78	1.00	80	2.78	1.06	0.01	0.4738
Crown Width (ft)	74	14.97	6.77	54	16.65	6.69	-0.56	0.2879
Age (yr)	78	26.49	2.85	53	27.26	2.46	-1.67	0.0493
Growth Years 1-5 (mm)	77	13.83	7.78	53	14.11	6.92	-0.21	0.4160
Growth Years 6-10 (mm)	77	22.76	11.16	53	22.92	8.79	-0.08	0.4667
Growth Years 11-15 (mm)	77	19.63	7.38	53	23.24	13.17	-1.81	0.0370
Growth Years 16-20 (mm)	66	17.36	6.78	50	18.68	8.82	-0.88	0.1895
Growth Years 21-25 (mm)	20	15.52	5.18	17	17.99	8.57	-1.04	0.1534
Growth Pith-Thin (mm)	76	79.67	29.18	52	88.56	33.71	-1.55	0.0626
Growth Years Thin + 1 (mm)	76	2.80	1.55	52	2.84	1.67	-0.13	0.4473
Growth Years Thin + 2 (mm)	76	3.50	2.02	52	3.62	1.91	-0.32	0.3668
Growth Years Thin + 3 (mm)	76	3.17	1.74	52	4.38	5.42	-1.56	0.0625
Growth Years Thin + 4 (mm)	76	2.58	1.67	52	2.76	1.51	-0.64	0.2624
Growth Thin-Bark (mm)	75	11.83	5.93	52	13.72	8.97	-1.33	0.0942
Growth Pith-Bark (mm)	75	91.02	34.71	52	101.52	38.68	-1.57	0.0600

* Crowns are classified from 1 (dominant trees) to 4 (suppressed trees).

Appendix B

Non-parametric statistical analysis of the > 12 foot, 0-6 foot and 6-12 foot areas of the Demonstration Area.

To confirm the findings of the parametric statistical tests, a series of non-parametric statistical tests were conducted. As with previous parametric tests, the data were analyzed by distance categories: trees within 6 feet of the corridor, trees 6 to 12 feet from the corridor, and trees greater than 12 feet from the corridor.

Prior to non-parametric analysis, cumulative relative frequency charts for DBH, total height, volume, growth before thinning, and growth after thinning were constructed to show the differences between the distributions of each distance class. As in the parametric analysis, the differences between the 0-12' and > 12' areas followed no obvious patterns. The Kruscal-Wallis test confirmed that the samples were from the same population (i.e. no significant differences between the sample groups at a p-level of 0.10).

The cumulative relative frequency chart for growth before thinning for the three data groups (Figure B.1) confirms that the trees in the 0-6' areas grew faster than trees in the other two groups, but the differences were not statistically significant at a p-level of 0.10. This could explain why the trees in the 6-12' areas had a bigger mean diameter than the trees in the > 12' areas. However, why these trees grew faster before thinning was not evident based on the available data.

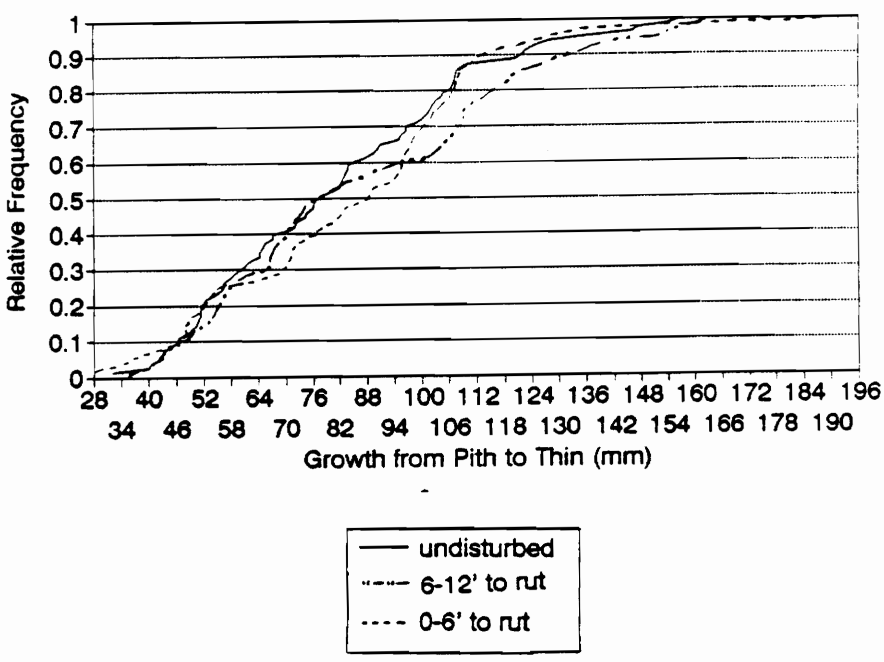

Figure B.1. Cumulative relative frequency chart of the growth before thinning for the Demonstration Area by distance class.

The cumulative relative frequency chart of tree diameters shows that sawlog production in the Demonstration Area was unsatisfactory, as 70% of the trees were less than 9 inches in DBH (Figure B.2). Less than 30% of the trees had volumes greater than 11 cubic feet (i.e. 9" DBH 50' tall) (Figure B.3). If the management objective of the thinning was to produce sawlogs, then too many small trees (less than 9 inches DBH) were left after thinning. Leaving such small trees is prudent only when the stand is spatially thinned instead of thinned from below (Smith 1986). Spatial thinning typically does not produce a quality sawlog stand because the smallest remaining trees either do not respond upon release or do not grow fast enough to reach sawlog size by the time of final harvest.

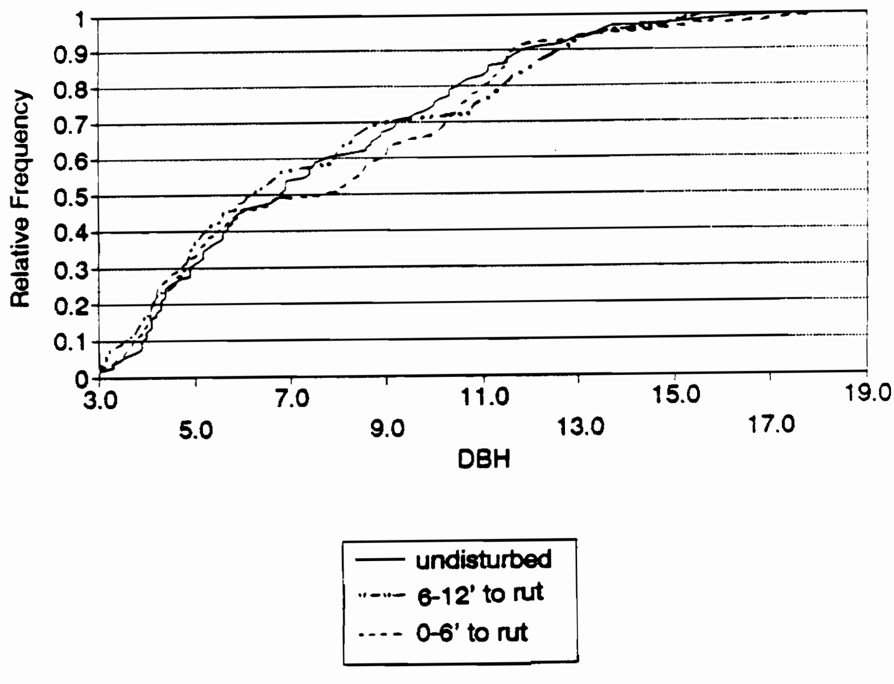

Figure B.2. Cumulative relative frequency of tree diameters on the >12', 6-12', and 0-6' areas of the Demonstration Area.

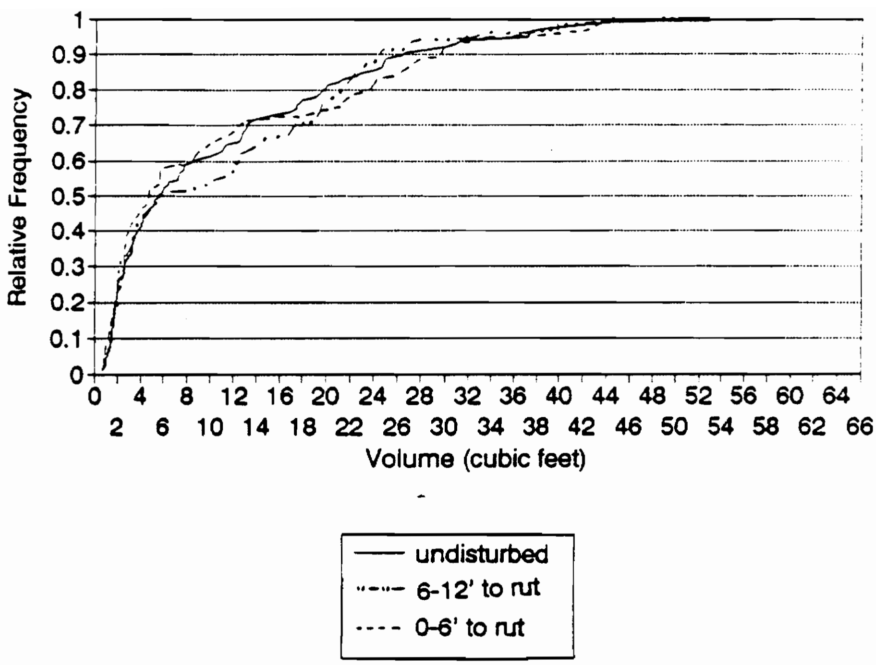

Figure B.3. Cumulative relative frequency chart of tree volumes for the > 12', 6-12', and 0-6' areas of the Demonstration Area.

Appendix C

Parametric statistical analysis of tree parameters for the comparisons of tree growth by diameter class, crown class and distance category in the Demonstration Area.

Comparisons of Tree Growth by Diameter Class

Clearly, growth of the largest trees was not limited by their proximity to disturbed soils, raising the question of whether smaller trees responded similarly. To answer this question, data from the > 12', 6-12' and 0-6' areas was separated into two inch diameter classes.

Tests were performed on the DBH, total height, and PAI after thinning. Neither DBH nor total height differed significantly in any diameter class (Table C.1). In each diameter class, the response to thinning was higher for the trees growing in the 0-6' areas than for those growing in the > 12' areas, but the differences were not significant at a p-level of 0.10. The 10.1-12 inches diameter class was the only exception; the trees growing in the > 12' areas grew better after thinning than did the trees growing in the 0-6' areas.

Table C.1. Post-thinning PAI of trees growing in > 12' and 0-6' areas of the Demonstration Area based on two inch diameter classes.

	Trees > 12' From Corridor			Trees 0-6' From Corridor			Statistics	
DBH (in.)	N	Mean	Std. Dev.	N	Mean	Std. Dev.	t-value	p-level
4.1-6"	18	1.51	0.67	12	1.63	0.70	-0.43	0.3357
6.1-8"	16	1.99	0.83	2	2.75	1.29	-0.80	0.2845
8.1-10"	16	3.47	0.59	14	3.51	0.71	-0.16	0.4378
10.1-12"	13	4.42	0.98	17	3.85	0.87	1.66	0.0546
12.1-14"	6	4.92	0.67	3	5.02	0.97	-0.16	0.4434
14.1-18"	4	4.44	0.57	4	4.11	1.14	0.52	0.3119

Comparison of Tree Growth by Crown Classification and Distance Category

Other comparisons of trees in the > 12' and 0-12' areas were based on crown class and distance from the corridor. The dominant trees growing more than 12 feet from the corridor were on average 3.6 inches larger in DBH than the dominant trees growing within six feet of the corridor (p=0.01 level) (Table C.2). Furthermore, the dominant trees in the > 12' areas had an average crown width of 22 feet, while the trees in 0-6' areas had average crown widths of only 15.6 feet, significant at a p=0.01 level. The average total height of the dominant trees growing more than 12 feet from the corridor was nine feet taller than the dominant trees growing within 6 feet of the corridor (significant at a p=0.05 level). Rather than increasing their height growth, the trees growing in the 0-6' areas probably increased their diameters and crown widths after the "training" trees (i.e. in crowded conditions, trees increase height growth instead of crown expansion) were removed during thinning.

When the trees growing in the >12' areas were compared to those 6-12 feet from the rut, no significant differences were found in diameter, total height, crown width, or height to the base of the live crown (p=0.10) (Table C.3).

Table C.2. Parameters of the dominant trees growing in >12', 0-6', and 6-12' areas of the Demonstration Area.

	Trees >12' From Corridor			Trees 0-6' From Corridor			Trees 6-12' From Corridor		
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	N	Mean	Std. Dev.
DBH (in.)	12	12.0	3.97	29	8.4	4.26	17	11.2	3.07
Total Height (ft)	12	60.3	15.01	29	51.3	14.94	17	60.6	9.12
Crown Width (ft)	12	22.3	8.09	28	15.4	7.79	17	20.5	6.34

In contrast, the co-dominant trees growing within 6 feet of the corridor were 0.7 inches larger than their counterparts growing more than 12 feet from the corridor (significant at a p=0.05 level). The crown widths of the co-dominant trees growing in the 0-6' areas were significantly larger than those of the trees in the >12' areas at a p=0.01 level. Total heights of the co-dominant trees growing in the 0-6' areas averaged two feet taller than those growing in the >12' areas (significant at a p=0.10 level). The trees growing more than 12 feet from the corridor and trees growing within 6 and 12 feet of the corridor were approximately the same height; however, the DBH of the trees growing in the 6-12' areas was significantly larger (p=0.10) by about 0.6 inches. The trees growing in the 6-12' areas also had slightly wider crowns than did the trees growing in the >12' areas, but this difference was not significant at a p-level of 0.10.

Table C.3. Parameters of the co-dominant trees growing >12', 0-6' and 6-12' from skidding corridors in the Demonstration Area.

	Trees >12' From Corridor			Trees 0-6' From Corridor			Trees 6-12' From Corridor		
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	N	Mean	Std. Dev.
DBH (in.)	51	9.7	1.88	45	10.4	2.05	32	10.34	2.42
Total Height (ft)	51	60.2	8.47	45	62.2	6.30	32	59.9	8.74
Crown width (ft)	51	16.8	4.97	45	19.2	5.23	32	18.2	5.31

The growth differences between the dominant trees in the >12' and 0-12' areas occurred because in the >12' areas most of the largest trees were inaccessible to the feller-buncher and were not removed. In the 0-6' areas, these trees were removed during the thinning operation to help with the profitability of the thinning operation. Even if this is the case, the dominant trees growing within six feet of the corridor did not respond as well to thinning, perhaps because of the severity of soil disturbance. Although the dominant trees growing in the 0-6' areas had more crown space, they failed to exploit this space fully. Perhaps the dominant trees growing in the 0-6' areas were growing at their maximum rate before thinning, so that thinning had little positive impact on their growth.

On the other hand, the co-dominant trees more than 12 feet from the corridor were not adequately thinned, forcing the trees to grow in an overcrowded condition and resulting in lack-luster growth after thinning. Such growth declines resulting from an improper thinning regime commonly occur in stands experiencing crown closure (Smith 1986). The co-dominant trees located between six and 12 feet of the corridor were only slightly larger than those growing in the >12' areas. The co-dominant trees in the 6-12' areas quickly responded to the openings created by thinning, growing rapidly until crown closure reoccurred, but, the trees growing in the >12' areas were only partially released, causing them to grow at a slightly slower pace.

Appendix D

Tables of tree parameters for the analysis of the trees growing more than 12 feet from the corridor versus trees within 12 feet of the corridor on 0-3 inch, 3-6 inch, >6 inch Ruts in the Demonstration Area.

Table D.1. Summary of all tree parameters measured for the trees > 12 feet from the corridor and trees adjacent to ruts less than 3 inches deep in the Demonstration Area.

	Trees >12' From Corridor			Trees 0-12' On 0-3" Ruts			Statistics	
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	t-value	p-level
DBH (ft)	109	7.39	3.30	32	6.56	3.59	1.18	0.1229
HT to Base Live Crown (ft)	74	34.04	7.33	22	32.64	8.97	0.67	0.2356
Total Height (ft)	109	50.37	12.35	32	46.59	14.91	1.31	0.0991
Crown Classification *	109	2.81	1.00	21	3.47	0.51	-4.54	0.0000+
Crown Width (ft)	74	14.97	6.77	22	14.09	6.92	0.53	0.3006
Age (yr)	78	26.49	2.85	19	27.47	2.74	-1.32	0.0991
Growth Years 1-5 (mm)	77	13.83	7.78	19	13.14	6.31	0.41	0.3434
Growth Years 6-10 (mm)	77	22.76	11.16	19	21.45	7.13	0.64	0.2635
Growth Years 11-15 (mm)	77	19.63	7.38	19	20.04	11.98	-0.14	0.4434
Growth Years 16-20 (mm)	66	17.36	6.78	18	16.57	8.40	0.37	0.3590
Growth Years 21-25 (mm)	20	15.52	5.18	8	17.41	6.29	-0.75	0.2330
Growth Pith-Thin (mm)	76	79.67	29.18	19	80.48	38.07	-0.01	0.5339
Growth Year Thin +1 (mm)	76	2.80	1.55	19	2.72	1.41	0.23	0.4100
Growth Year Thin +2 (mm)	76	3.50	2.02	19	3.34	1.74	0.35	0.3641
Growth Year Thin +3 (mm)	76	3.17	1.74	19	3.42	1.84	-0.53	0.2995
Growth Year Thin +4 (mm)	76	2.58	1.67	19	2.50	1.20	0.26	0.3988
Growth Thin-Bark (mm)	75	11.83	5.93	19	12.07	5.52	-0.14	0.4468
Growth Pith-Bark (mm)	75	91.02	34.71	19	94.83	48.97	-0.30	0.3846

* Crowns are classified from 1 (dominant trees) to 4 (suppressed trees).

\+ Probability less than 0.0001

Table D.2. Summary of all tree parameters measured for the trees > 12 feet from the corridor and trees adjacent to ruts 3-6 inches deep in the Demonstration Area.

	Trees >12' From Corridor			Trees 0-12' On 3.1-6" Ruts			Statistics	
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	t-value	p-level
DBH (in)	109	7.39	3.30	37	7.72	3.34	-0.50	0.3101
HT to Base Live Crown (ft)	74	34.04	7.33	25	34.94	5.88	-0.62	0.2692
Total Height (ft)	109	50.37	12.35	36	53.25	13.82	-1.11	0.1351
Crown Classification *	109	2.81	1.00	16	3.63	0.72	-4.01	0.0002
Crown Width (ft)	74	14.97	6.77	25	18.08	6.40	-2.07	0.0222
Age (yr)	78	26.49	2.85	25	27.52	2.69	-1.55	0.0637
Growth Years 1-5 (mm)	77	13.83	7.78	24	15.25	9.72	-0.65	0.2591
Growth Years 6-10 (mm)	77	22.76	11.16	25	23.29	8.46	-0.25	0.4036
Growth Years 11-15 (mm)	77	19.63	7.38	25	23.39	7.64	-2.16	0.0184
Growth Years 16-20 (mm)	66	17.36	6.78	24	19.05	5.69	-1.18	0.1208
Growth Years 21-25 (mm)	20	15.52	5.18	13	16.02	4.90	-0.28	0.3903
Growth Pith-Thin (mm)	76	79.67	29.18	25	91.59	25.58	-1.95	0.0286
Growth Year Thin + 1 (mm)	76	2.80	1.55	25	3.19	1.26	-1.27	0.1054
Growth Year Thin + 2 (mm)	76	3.50	2.02	25	3.68	1.63	-0.43	0.3341
Growth Year Thin + 3 (mm)	76	3.17	1.74	25	3.55	1.65	-0.98	0.1662
Growth Year Thin + 4 (mm)	76	2.58	1.67	25	2.98	1.16	-1.31	0.0979
Growth Thin-Bark (mm)	75	11.83	5.93	25	13.61	4.91	-1.45	0.0761
Growth Pith-Bark (mm)	75	91.02	34.71	25	105.18	28.79	-1.99	0.0262

* Crowns are classified from 1 (dominant trees) to 4 (suppressed trees).

Table D.3. Summary of all tree parameters measured for the trees > 12 feet from the corridor and trees adjacent to ruts greater than 6 inches deep in the Demonstration Area.

	Trees >12' From Corridor			Trees 0-12' On 6-24" ruts			Statistics	
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	t-value	p-level
DBH (in)	109	7.39	3.30	11	8.95	4.14	-1.21	0.1252
Hgt. to Base Live Crown (ft)	74	34.04	7.33	9	32.78	6.36	0.55	0.2958
Total Height (ft)	109	50.37	12.35	10	54.30	14.01	-0.86	0.2048
Crown Classification *	109	2.81	1.00	3	3.67	0.58	-2.48	0.0448
Crown Width (ft)	74	14.97	6.77	9	17.56	6.19	-1.17	0.1334
Age (yr)	78	26.49	2.85	9	27.89	3.01	-1.27	0.1161
Growth Years 1-5 (mm)	77	13.83	7.78	9	15.32	5.68	-0.71	0.2440
Growth Years 6-10 (mm)	77	22.76	11.16	9	24.51	11.86	-0.42	0.3423
Growth Years 11-15 (mm)	77	19.63	7.38	9	21.25	6.63	-0.69	0.2530
Growth Years 16-20 (mm)	66	17.36	6.78	9	23.77	7.25	-2.51	0.0146
Growth Years 21-25 (mm)	20	15.52	5.18	5	21.69	7.01	-1.84	0.0574
Growth Pith-Thin (mm)	76	79.67	29.18	9	102.15	38.06	-1.71	0.0604
Growth Year T+1 (mm)	76	2.80	1.55	9	3.82	1.24	-2.25	0.0220
Growth Year T+2 (mm)	76	3.50	2.02	9	3.84	1.18	-0.72	0.2397
Growth Year T+3 (mm)	76	3.17	1.74	9	3.59	1.12	-0.99	0.1692
Growth Year T+4 (mm)	76	2.58	1.67	9	3.16	1.67	-0.98	0.1745
Growth Thin-Bark (mm)	75	11.83	5.93	9	14.61	4.78	-1.58	0.0704
Growth Pith-Bark (mm)	75	91.02	34.71	9	117.01	41.90	-1.77	0.0535

* Crowns are classified from 1 (dominant trees) to 4 (suppressed trees).

Appendix E

Tables of tree parameters for the > 12 foot, 0-6 foot and 6-12 foot areas of the Deer Camp Area.

Table E.1. Summary of all tree parameters measured for trees > 12 feet from the corridor and trees 0-12 feet from the corridor in the Deer Camp Area.

	Trees >12' From Corridor			Trees 0-12' From Corridor			Statistics	
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	t-value	p-level
DBH (in)	92	9.06	3.44	154	9.61	3.30	-1.24	0.1075
HT to Base Live Crown (ft)	68	38.96	5.16	126	40.13	4.54	-1.57	0.0592
Total Height (ft)	68	68.74	8.27	126	69.45	7.15	-0.60	0.2737
Crown Width (ft)	68	17.16	6.35	126	16.65	7.44	0.50	0.3079
Age (yr)	65	31.36	3.29	122	31.06	2.97	0.62	0.2678
Growth Years 1-5 (mm)	65	13.64	6.49	122	13.99	7.33	-0.34	0.3690
Growth Years 6-10 (mm)	65	23.70	9.83	122	24.13	8.18	-0.30	0.3813
Growth Years 11-15 (mm)	65	25.43	8.99	122	25.23	8.19	0.15	0.4489
Growth Years 16-20 (mm)	64	19.92	9.00	122	19.46	7.47	0.35	0.3644
Growth Years 21-25 (mm)	46	19.12	16.06	83	16.57	6.23	1.04	0.1526
Growth Years 26-30 (mm)	10	16.80	6.39	14	14.81	4.85	0.83	0.2105
Growth Pith-Thin (mm)	65	101.06	29.10	122	101.03	25.83	0.00	0.4976
Growth Year Thin + 1 (mm)	67	2.40	1.08	123	2.46	1.06	-0.41	0.3424
Growth Year Thin + 2 (mm)	67	3.82	1.50	123	3.91	1.61	-0.42	0.3373
Growth Year Thin + 3 (mm)	67	4.33	1.52	123	4.49	1.65	-0.69	0.2472
Growth Year Thin + 4 (mm)	67	4.14	1.57	123	4.33	1.62	-0.77	0.2208
Growth Year Thin + 5 (mm)	67	2.27	0.95	123	2.46	0.80	-1.43	0.0775
Growth Thin-Bark (mm)	67	16.72	5.46	123	17.59	5.77	-1.03	0.1521
Growth Pith-Bark (mm)	65	117.86	32.65	122	118.77	29.02	-0.19	0.4247

Table E.2. Summary of all tree parameters measured for trees > 12 feet from the corridor and trees 0-6 feet from the corridor in the Deer Camp Area.

	Trees >12' From Corridor			Trees 0-6' From Corridor			Statistics	
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	t-alue	p-level
DBH (in)	92	9.06	3.44	94	10.20	3.17	-2.37	0.0095
HT to Base Live Crown (ft)	68	38.96	5.16	82	40.18	4.36	-1.15	0.1259
Total Height (ft)	68	68.74	8.27	82	70.17	6.70	-0.26	0.3975
Crown Classification *	92	2.75	2.19	94	2.14	0.93	2.43	0.0082
Crown Width (ft)	68	17.16	6.35	82	17.47	19.02	-0.26	0.3975
Age (yr)	65	31.36	3.29	80	31.04	2.86	0.64	0.2619
Growth Years 1-5 (mm)	65	13.64	6.49	80	13.80	7.36	-0.14	0.4447
Growth Years 6-10 (mm)	65	23.70	9.83	80	24.40	8.37	-0.46	0.3249
Growth Years 11-15 (mm)	65	25.43	8.99	80	25.99	7.94	-0.40	0.3462
Growth Years 16-20 (mm)	64	19.92	9.00	80	20.01	7.95	-0.01	0.4756
Growth Years 21-25 (mm)	46	19.12	16.06	55	17.32	6.60	0.71	0.2398
Growth Years 26-30 (mm)	10	16.80	6.39	8	15.42	4.27	0.55	0.2959
Growth Pith-Thin (mm)	65	101.06	29.10	80	102.98	25.85	-0.42	0.3392
GrowthYear Thin + 1 (mm)	67	2.40	1.08	81	2.61	1.02	-1.21	0.1149
Growth Year Thin + 2 (mm)	67	3.82	1.50	81	4.12	1.57	-1.21	0.1145
Growth Year Thin + 3 (mm)	67	4.33	1.52	81	4.73	1.58	-1.57	0.0592
Growth Year Thin + 4 (mm)	67	4.14	1.57	81	4.45	1.39	-1.24	0.1095
Growth Year Thin + 5 (mm)	67	2.27	0.95	81	2.58	0.76	-2.15	0.0168
Growth Thin-Bark (mm)	67	16.72	5.46	81	18.42	5.36	-1.91	0.0293
Growth Pith-Bark (mm)	65	117.86	32.65	80	121.64	28.85	-0.73	0.2333

* Crowns are classified from 1 (dominant trees) to 4 (suppressed trees).

Table E.3. Summary of all tree parameters measured for trees > 12 feet from the corridor and trees 6-12 feet from the corridor in the Deer Camp Area.

	Trees >12' From Corridor			Trees 6-12' From Corridor			Statistics	
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	t-value	p-level
DBH (in)	92	9.06	3.44	59	8.75	3.28	0.47	0.3203
Hgt. to Base Live Crown (ft)	68	38.96	5.16	44	40.02	4.90	-0.44	0.3317
Total Height (ft)	68	68.74	8.27	44	68.11	7.83	0.32	0.3742
Crown Classification *	92	2.75	2.19	59	2.51	1.04	0.91	0.1820
Crown Width (ft)	68	17.16	6.35	44	15.11	4.90	1.91	0.0294
Age (yr)	65	31.36	3.29	42	31.12	3.19	0.23	0.4100
Growth Years 1-5 (mm)	65	13.64	6.49	42	14.35	7.34	-0.55	0.2907
Growth Years 6-10 (mm)	65	23.70	9.83	42	23.62	7.89	0.34	0.3671
Growth Years 11-15 (mm)	65	25.43	8.99	42	23.77	8.57	0.60	0.2754
Growth Years 16-20 (mm)	64	19.92	9.00	42	18.43	6.44	0.72	0.2363
Growth Years 21-25 (mm)	46	19.12	16.06	28	15.09	5.24	0.76	0.2239
Growth Years 26-30 (mm)	10	16.80	6.39	6	14.01	5.85	0.74	0.2369
Growth Pith-Thin (mm)	65	101.06	29.10	42	97.32	25.69	0.41	0.3415
GrowthYear Thin + 1 (mm)	67	2.40	1.08	42	2.19	1.11	0.71	0.2392
Growth Year Thin + 2 (mm)	67	3.82	1.50	42	3.51	1.63	1.12	0.1324
Growth Year Thin + 3 (mm)	67	4.33	1.52	42	4.03	1.72	1.08	0.1421
Growth Year Thin + 4 (mm)	67	4.14	1.57	42	4.09	1.98	0.20	0.4230
Growth Year Thin + 5 (mm)	67	2.27	0.95	42	2.25	0.85	0.23	0.4104
Growth Thin-Bark (mm)	67	16.72	5.46	42	15.98	6.24	0.80	0.2138
Growth Pith-Bark (mm)	65	117.86	32.65	42	113.33	28.88	0.52	0.3031

* Crowns are classified from 1 (dominant trees) to 4 (suppressed trees).

Appendix F

Non-parametric statistical analysis of the > 12 foot, 0-6 foot and 6-12 foot areas of the Deer Camp Area.

Non-parametric statistical analysis was used to confirm the findings of the parametric tests for the Deer Camp Area. The first step in this process involved computation of cumulative relative frequency charts for the DBH, total height, volume, growth since thinning, and growth from the pith to the point of thinning for trees in the undisturbed, heavily disturbed, and slightly disturbed areas. These charts show the distributions of the tree parameters that the non-parametric tests use to calculate their test statistics. The differences between the separate graphs were clear, and correlated with the results from the parametric statistical analysis.

The Kolmogorov-Smirnov (KS) test was performed on the data to confirm that the trees growing within six feet of the corridor in the Deer Camp Area were not from the same population as the trees growing in the 6-12' and >12' areas ($p=0.05$). The KS test found that the trees growing in the 0-6' areas had larger diameters ($p=0.05$) than the trees growing more than six feet from the rut. The trees growing in all disturbance classes had the same maximum and minimum tree size; however, the distributions were different (Figure F.1). Approximately 40% of the trees growing more than 12 feet from the corridor were smaller than 8.5 inches in DBH (Figure F.1). But in the 0-6' areas, less than 20% of the trees had diameters smaller than 8.5 inches. The trees growing in the 6-12' areas had a diameter distribution similar to those growing in the >12' areas, with no significant differences at a $p=0.05$ level. The trees growing in the 0-6' areas were larger than the trees growing in the other areas because they grew faster both before (Figure F.2) and after thinning (Figure F.3).

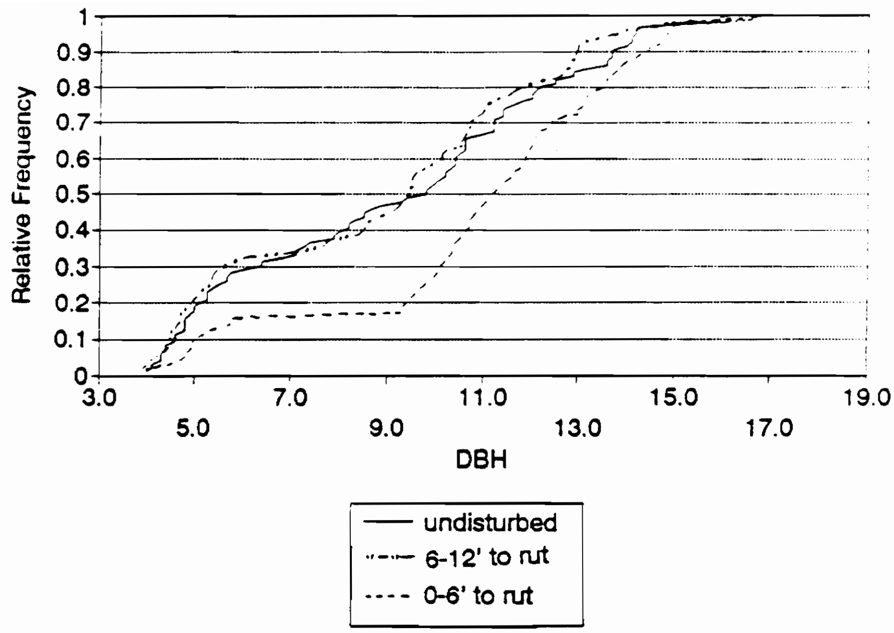

Figure F.1. Cumulative relative frequency of DBH for trees growing in the >12', 6-12', and 0-6' areas of the Deer Camp Area.

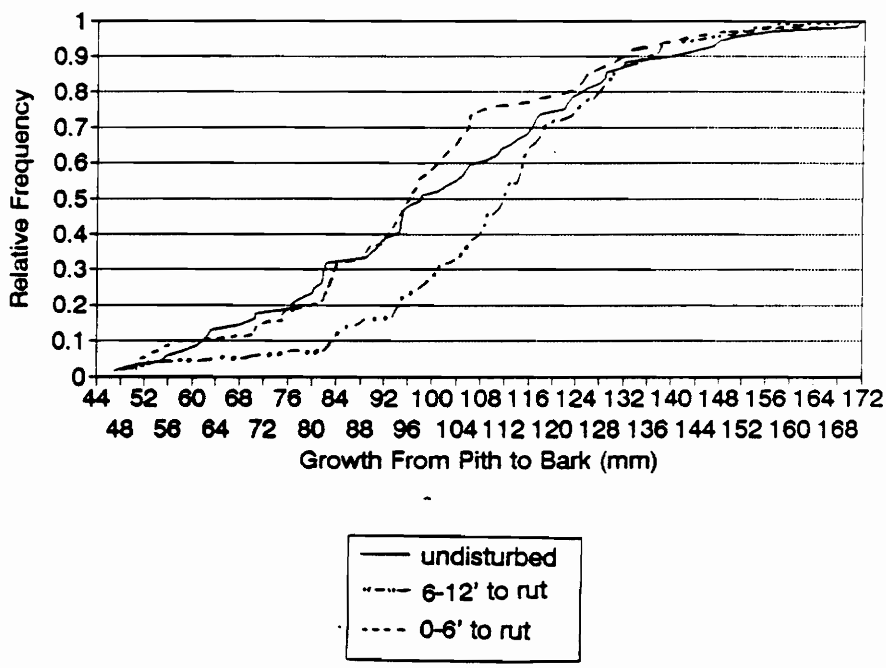

Figure F.2. Cumulative relative frequency of growth before thinning of trees growing in the >12', 6-12', and 0-6' areas of the Deer Camp Area.

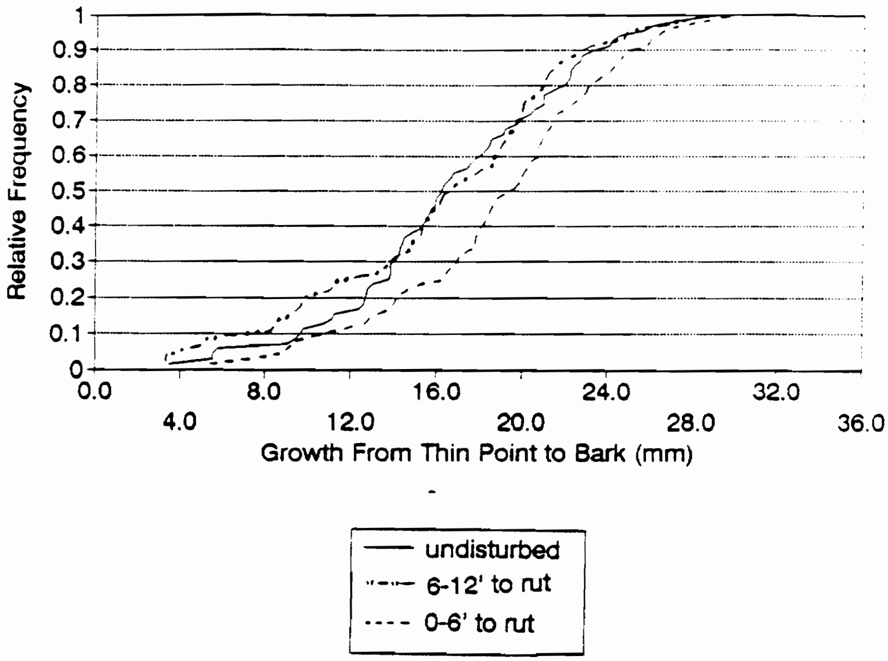

Figure F.3. Cumulative relative frequency of radial growth after thinning of trees growing in the >12', 6-12', and 0-6' areas of the Deer Camp Area.

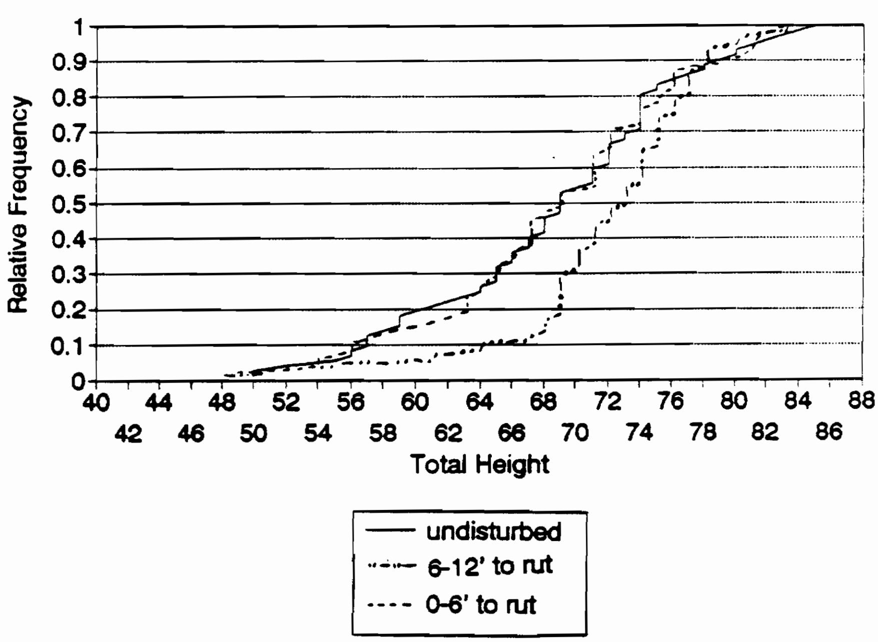

Figure F.4. Cumulative relative frequency of total height of trees growing in the >12', 6-12', and 0-6' areas of the Deer Camp Area.

The same trend was found for the total height of trees. The trees growing within 6 feet of the corridor were taller than the trees growing in the 6-12' and > 12' areas, significant at a p=0.05 level. Approximately 15% of the trees growing in the 0-6' areas were less than 68 feet tall, compared to 46% of the trees growing in the 6-12' and > 12' areas (Figure F.4). Because the diameters and heights of the trees growing in the 0-6' areas were significantly larger than those of the trees growing in the > 12' and 6-12' areas, the average volume of the trees within 6 feet of the corridor was also significantly larger (p=0.05) (Figure F.5).

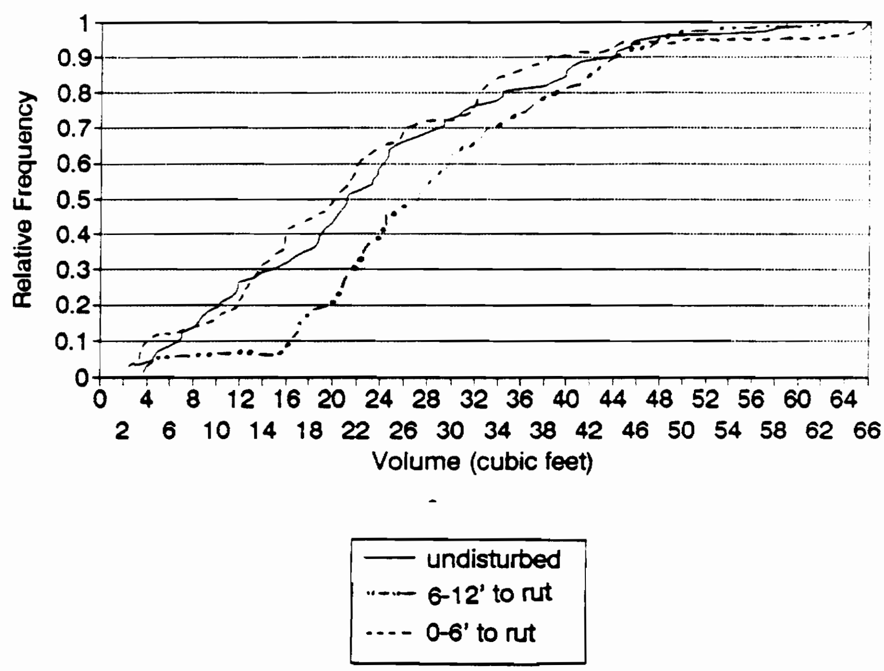

Figure F.5. Cumulative relative frequency of tree volumes in > 12', 6-12', and 0-6' areas of the Deer Camp Area.

Appendix G

Parametric statistical analysis of the tree parameters for the comparisons of tree growth by diameter class, crown class and distance category in the Deer Camp Area.

Comparisons of Tree Growth by Diameter Class

To determine if trees of certain sizes responded to thinning better than others, tests were conducted on groups based on tree diameter and distance class. The trees growing in the >12', 0-6', and 6-12' areas were divided into two-inch diameter classes and three major parameters were tested: DBH, total height, and total radial growth since thinning. For each diameter class, no significant differences in DBH were found between trees in the >12' and 0-6' areas, although the trees growing within 6 feet of the corridor tended to be larger than the trees growing more than 12 feet from the corridor (Table G.1). Results of total height comparisons were mixed. In the four inch diameter class, the trees growing in the >12' areas were significantly taller (p=0.04) than the trees growing in 0-6' areas, but in the 6-8, 8-10, and 10-12 inch diameter classes, the trees growing within 6 feet of the corridor were taller. These height differences were significant in the 6-8 inch (p=0.11) and 8-10 inch (p=0.07) classes.

Table G.1. DBH, total height, and total radial growth after thinning for each diameter class of trees in the >12' and 0-6' areas of the Deer Camp Area.

	DBH (in.)			Total Height (ft)			Radial Growth From Thin to Bark		
	N	t-value	p-level	N	t-value	p-level	N	t-value	p-level
4.1-6"	13.8	-0.25	0.4021	4.9	3.71	0.0069	3.9	-0.31	0.3865
6.1-8"	9.2	-0.75	0.2365	11.2	-1.85	0.0454	7.9	-1.37	0.1038
8.1-10	25.4	-0.32	0.3738	20.2	-1.97	0.0313	32.6	-1.52	0.0695
10.1-12"	47.9	-0.49	0.3134	42.1	-0.49	0.3134	47.5	-0.62	0.2679
12.1-14"	26.0	0.96*	0.1718	16.5	0.49	0.3160	28.3	0.003	0.4875
14.1-18"	14.2	-0.16 +	0.4390	17.9	4.22	0.0030	13.6	-4.73	0.3217

In the 14-18 inch diameter class, the trees growing in the >12' areas were significantly taller than the trees growing in the 0-6' areas (Table G.1). In all but one diameter class (12-14 inch) the trees in the 0-6' areas responded with more radial growth than did the trees growing in undisturbed area (p=0.48). As in the Demonstration Area, the small sample sizes and large variances within the groups clouded the effects of the thinning upon residual tree growth.

Comparison of Tree Growth by Crown Classification and Disturbance Category

The crown classification was also used to compare trees growing in the 6-12' and 0-6' areas with those in the >12' areas. No significant differences existed between the dominant trees in each distance class (Table G.2). The dominant trees growing in the >12' areas were not significantly smaller than the dominants growing in the 0-12' areas because they were above the rest of the canopy and therefore were not limited by crown space.

Table G.2. Measured parameters of dominant trees growing in the >12', 0-6', and 6-12' areas of the Deer Camp Area.

	Trees >12' From Corridor			Trees 0-6' From Corridor			Trees 6-12' From Corridor		
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	N	Mean	Std. Dev.
DBH (in.)	46	14.08	1.52	73	14.01	1.73	27	13.79	1.88
Height to Base of Live Crown (ft)	46	39.24	4.22	73	40.11	4.51	27	39.26	5.30
Total Height (ft)	46	77.39	4.57	73	76.92	3.61	27	76.82	3.88
Crown Width (ft)	46	22.02	4.89	73	22.19	4.41	27	22.04	4.73

When the co-dominant trees in the 0-6' and >12' areas were compared, the those in the >12' areas tended to be smaller than their counterparts in the 0-6' areas ($p=0.40$).

Table G.3. Measured parameters of co-dominant trees growing in the >12' and 0-6' areas of the Deer Camp Area.

	Trees >12' From corridor			Trees 0-6' From Corridor			Statistics	
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	t-value	p-level
DBH (in.)	99	10.76	1.55	116	10.86	1.62	-0.44	0.3312
Hgt. to Base of Live Crown (ft)	99	40.55	4.48	116	40.72	4.93	-0.26	0.3956
Total Height (ft)	99	70.12	5.17	116	70.44	4.16	-0.49	0.3115
Crown Width (ft)	99	16.72	3.97	116	17.05	6.65	-0.46	0.3247

The co-dominant trees growing more than 12 feet from the corridor were 0.5 inches larger in DBH (p=0.02) than the co-dominant trees growing in the 6-12' areas (Table G.4). The co-dominant trees growing in the > 12' areas also had significantly larger crown widths (p=0.06).

Table G.4. Measured parameters of co-dominant trees growing in the > 12' and 6-12' areas of the Deer Camp Area.

	Trees > 12' From Corridor			Trees 6-12' From Corridor			Statistics	
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	t-value	p-level
DBH (in.)	99	10.76	1.55	58	10.29	1.37	1.96	0.0258
Hgt. to Base of Live Crown (ft)	99	40.55	4.48	58	40.95	4.70	-0.53	0.2996
Total Height (ft)	99	70.12	5.17	58	69.66	4.50	0.59	0.2772
Crown Width (ft)	99	16.72	3.97	58	15.64	4.31	1.56	0.0608

The fact that the co-dominant trees growing in the 0-6' and 6-12' areas were larger than those growing in the > 12' areas supports the theory that crown space was the most important factor in growth after thinning. Without crown space, the residual trees could not increase their growth rates much higher than their pre-thinning growth rates.

Appendix H

Tables of tree parameters for the analysis of the trees more than 12 feet from the corridor versus trees 0-12 feet from corridor on 0-3 inch, 3-6 inch, >6 inch Ruts in the Deer Camp Area.

Table H.1. Summary of all tree parameters of the trees growing > 12 feet from the corridor and trees growing adjacent to ruts 0-3 inches deep in the Deer Camp Area.

	Trees >12' From Corridor			Trees 0-12' On 0-3" ruts			Statistics	
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	t-value	p-level
DBH (in)	92	9.06	3.44	122	9.69	3.49	-1.32	0.0939
Hgt to Base Live Crown (ft)	68	38.96	5.16	96	40.19	4.77	-1.55	0.0612
Total Height (ft)	68	68.74	8.27	96	70.36	7.10	-1.32	0.0951
Crown Classification *	92	2.75	2.19	122	2.31	1.06	1.52	0.0655
Crown Width (ft)	68	17.16	6.35	96	17.49	8.01	-0.29	0.3854
Age (yr)	65	31.37	3.29	93	31.36	3.12	0.00	0.4972
Growth Years 1-5 (mm)	65	13.64	6.49	93	14.29	7.99	-0.56	0.2867
Growth Years 6-10 (mm)	65	23.70	9.83	93	24.15	8.52	-0.30	0.3823
Growth Years 11-15 (mm)	65	25.43	8.99	93	25.42	8.20	0.00	0.4989
Growth Years 16-20 (mm)	64	19.92	9.00	93	20.54	7.85	-0.45	0.3269
Growth Years 21-25 (mm)	46	19.12	16.06	63	17.39	6.26	-0.37	0.3574
Growth Years 26-30 (mm)	10	16.80	6.39	12	15.33	5.01	0.59	0.2814
Growth Pith-Thin (mm)	65	101.06	29.10	93	104.10	25.88	-0.68	0.2501
GrowthYear Thin + 1 (mm)	67	2.40	1.08	94	2.54	1.10	-0.79	0.2153
Growth Year Thin + 2 (mm)	67	3.82	1.50	94	4.04	1.67	-0.89	0.1872
Growth Year Thin + 3 (mm)	67	4.33	1.52	94	4.56	1.70	-0.90	0.1836
Growth Year Thin + 4 (mm)	67	4.14	1.57	94	4.36	1.62	-0.85	0.1977
Growth Year Thin + 5 (mm)	67	2.27	0.95	94	2.47	0.76	-1.42	0.0785
Growth Thin-Bark (mm)	67	16.72	5.46	94	17.92	5.81	-1.33	0.0921
Growth Pith-Bark (mm)	65	117.86	32.65	93	122.21	29.20	-0.86	0.1957

* Crowns are classified from 1 (dominant trees) to 4 (suppressed trees).

Table H.2. Summary of all tree parameters of the trees growing > 12 feet from the corridor and trees growing adjacent to ruts > 6 inches deep in the Deer Camp Area.

	Trees >12' From Corridor			Trees 0-12' On 6-24" Ruts			Statistics	
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	t-value	p-level
DBH (in)	92	9.06	3.44	9	10.76	3.28	-1.48	0.0853
Hgt. to Base Live Crown (ft)	68	38.96	5.16	8	39.38	3.99	-0.27	0.3956
Total Height (ft)	68	68.74	8.27	8	69.13	11.04	-0.01	0.4627
Crown Classification *	92	2.75	2.19	9	2.22	0.97	0.91	0.1928
Crown Width (ft)	68	17.16	6.35	8	17.75	4.20	-0.35	0.3656
Age (yr)	65	31.37	3.29	8	30.12	1.36	1.98	0.0301
Growth Years 1-5 (mm)	65	13.64	6.49	8	14.66	5.24	-0.51	0.3117
Growth Years 6-10 (mm)	65	23.70	9.83	8	28.74	5.79	-2.12	0.0264
Growth Years 11-15 (mm)	65	25.43	8.99	8	31.01	8.41	-1.76	0.0547
Growth Years 16-20 (mm)	64	19.92	9.00	8	18.78	4.80	0.56	0.2918
Growth Years 21-25 (mm)	46	19.12	16.06	5	18.39	7.88	-0.40	0.3545
Growth Years 26-30 (mm)	10	16.80	6.39	0	—	—	—	—
Growth Pith-Thin (mm)	65	101.06	29.10	8	110.44	25.18	-0.98	0.1758
GrowthYear Thin + 1 (mm)	67	2.40	1.08	8	2.45	1.31	-0.11	0.4557
Growth Year Thin + 2 (mm)	67	3.82	1.50	8	3.70	1.86	0.18	0.4321
Growth Year Thin + 3 (mm)	67	4.33	1.52	8	4.40	2.27	-0.01	0.4662
Growth Year Thin + 4 (mm)	67	4.14	1.57	8	4.00	2.13	0.18	0.4303
Growth Year Thin + 5 (mm)	67	2.27	0.95	8	2.16	0.78	0.37	0.3586
Growth Thin-Bark (mm)	67	16.72	5.46	8	16.92	8.03	-0.01	0.4739
Growth Pith-Bark (mm)	65	117.86	32.65	8	127.33	31.77	-0.79	0.2241

* Crowns are classified from 1 (dominant trees to 4 (suppressed trees).

Table H.3. Summary of all tree parameters of the trees growing > 12 feet from the corridor and trees growing adjacent to ruts 3-6 inches deep in the Deer Camp Area.

	Trees >12' From Corridor			Trees 0-12' On 3.1-6" Ruts			Statistics	
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	t-value	p-level
DBH (ft)	92	9.06	3.44	7	10.51	1.70	-1.98	0.0357
Hgt. to Base Live Crown (ft)	68	38.96	5.16	7	36.71	2.81	1.82	0.0471
Total Height (ft)	68	68.74	8.27	7	66.71	4.27	1.06	0.1535
Crown Classification *	92	2.75	2.19	7	2.00	—	—	—
Crown Width (ft)	68	17.16	6.35	7	14.14	3.08	2.16	0.0241
Age	65	31.37	3.29	6	31.33	1.97	0.04	0.4845
Growth Years 1-5 (mm)	65	13.64	6.49	6	11.41	3.61	1.33	0.1064
Growth Years 6-10 (mm)	65	23.70	9.83	6	28.24	6.71	-1.51	0.0843
Growth Years 11-15 (mm)	65	25.43	8.99	6	28.71	4.92	-1.43	0.0923
Growth Years 16-20 (mm)	64	19.92	9.00	6	18.48	5.15	0.61	0.2801
Growth Years 21-25 (mm)	46	19.12	16.06	6	14.02	4.36	1.45	0.0902
Growth Years (26-30 (mm)	10	16.80	6.39	1	13.62	—	—	—
Growth Pith-Thin (mm)	65	101.06	29.10	6	104.17	16.07	-0.42	0.3431
Growth Year T+1 (mm)	67	2.40	1.08	6	2.44	0.49	-0.19	0.4257
Growth Year T+2	67	3.82	1.50	6	3.86	1.05	-0.01	0.4627
Growth Year T+3 (mm)	67	4.33	1.52	6	4.87	1.04	-1.16	0.1397
Growth Year T+4 (mm)	67	4.14	1.57	6	4.86	0.99	-1.60	0.0737
Growth Year T+5 (mm)	67	2.27	0.95	6	2.39	0.37	-0.67	0.257
Growth Thin-Bark (mm)	67	16.72	5.46	6	18.36	3.08	-1.16	0.1385
Growth Pith-Bark (mm)	65	117.86	32.65	6	122.45	15.89	-0.60	0.2803

Appendix I

Tables of all tree parameters of the undamaged and damaged trees in the Demonstration Area.

Table I.1. Summary of tree parameters of the undamaged and damaged trees growing more than 12 feet from the corridor in the Demonstration Area.

	Undamaged Trees			Damaged Trees			Statistics	
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	t-value	p-level
DBH (in	109	7.40	3.30	10	8.62	3.62	-1.03	0.1628
Hgt to Base Live Crown (ft)	74	34.04	7.33	7	33.43	5.03	0.29	0.3878
Total Height (ft)	109	50.37	12.35	10	55.50	15.22	-1.04	0.1624
Crown Classification *	109	2.81	1.00	10	2.60	1.08	0.59	0.2846
Crown Width (ft)	74	14.97	6.77	7	20.14	5.67	-2.27	0.0267
Tree Volume (cu ft)	109	10.50	11.50	10	15.30	12.68	-1.16	0.1362
Age (yr)	77	26.55	2.82	7	27.00	1.63	-0.65	0.2635
Growth Years 1-5 (mm)	77	13.83	7.78	7	20.07	10.53	-1.53	0.0849
Growth Years 6-10 (mm)	77	22.77	11.16	7	29.44	11.74	-1.45	0.0957
Growth Years 11-15 (mm)	77	19.62	7.38	7	25.35	3.81	-3.44	0.0025
Growth Years 16-20 (mm)	66	17.36	6.78	7	19.50	6.45	-0.83	0.2146
Growth Years 21-25 (mm)	20	15.52	1.17	1	17.84	—	—	—
Growth Pith-Thin (mm)	76	79.67	29.18	7	101.31	23.82	-2.25	0.0271
5-7 Year PAI (mm/yr)	48	3.00	1.17	7	3.90	1.74	-1.32	0.1141
Growth Year Thin+1 (mm)	76	2.80	1.55	7	3.77	1.72	-1.43	0.0983
Growth Year Thin+2 (mm)	76	3.51	2.02	7	5.17	1.47	-2.77	0.0108
Growth Year Thin+3 (mm)	76	3.17	1.74	7	4.99	1.33	-3.36	0.0042
Growth Year Thin+4 (mm)	76	2.58	1.68	7	3.47	0.96	-2.15	0.0272
Growth Thin-Bark (mm)	76	11.88	5.90	6	17.19	4.64	-2.64	0.0167
Thin PAI (mm/yr)	76	2.97	1.48	6	4.30	1.16	-2.64	0.0167
Growth Pith-Bark (mm)	76	91.30	34.56	6	120.57	28.32	-2.40	0.0239

* Crowns are classified from 1 (dominant trees) to 4 (suppressed trees).

Table I.2. Summary of tree parameters of the undamaged and damaged trees growing 0-6 feet from the corridor in the Demonstration Area

	Undamaged Trees			Damaged Trees			Statistics	
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	t-value	p-level
DBH (in)	81	7.41	3.58	19	7.97	2.89	-0.73	0.2367
Hgt. to Base Live Crown (ft)	57	33.52	7.33	17	30.65	7.54	1.39	0.0885
Total Height (ft)	79	50.60	14.44	19	49.90	12.71	0.21	0.4176
Crown Classification *	40	3.55	0.60	19	2.63	0.90	4.06	0.0002
Crown Width (ft)	57	16.42	6.67	17	13.06	5.75	2.04	0.0250
Tree Volume (cu ft)	79	11.56	12.56	19	11.06	8.80	0.21	0.4194
Age (yr)	54	27.50	2.73	17	24.88	4.15	2.44	0.0119
Growth Years 1-5 (mm)	53	14.34	7.93	17	18.66	9.82	-1.65	0.0561
Growth Years 6-10 (mm)	54	22.80	8.50	17	24.07	9.04	-0.54	0.3056
Growth Years 11-15 (mm)	54	21.72	9.21	17	19.15	8.35	1.08	0.1445
Growth Years 16-20 (mm)	52	18.20	7.37	13	16.07	6.72	1.29	0.1051
Growth Years 21-25 (mm)	26	17.54	5.92	4	15.41	2.39	1.28	0.1109
Growth Pith-Thin (mm)	54	88.73	33.01	17	78.43	25.25	1.36	0.0917
Pre-Thin PAI (mm/yr)	25	2.85	1.21	16	2.89	1.36	-0.01	0.4644
Growth Year Thin+1 (mm)	54	3.11	1.34	17	2.80	2.01	0.59	0.2806
Growth Year Thin+2 (mm)	54	3.56	1.58	17	3.31	2.34	0.41	0.3415
Growth Year Thin+3 (mm)	54	3.48	1.62	17	3.33	2.20	0.25	0.4018
Growth Year Thin+4 (mm)	54	2.82	1.27	17	2.47	1.41	0.91	0.1867
Growth Thin-Bark (mm)	54	13.12	5.12	17	11.65	7.51	0.76	0.2285
Post-Thin PAI (mm/yr)	54	3.28	1.28	17	2.91	1.88	0.76	0.2285
Growth Pith-Bark (mm)	54	102.69	39.35	17	90.15	31.64	1.30	0.1008

* Crowns are classified from 1 (dominant trees) to 4 (suppressed trees).

Table I.3. Summary of tree parameters of the undamaged and damaged trees growing 6-12 feet from the corridor in the Demonstration Area

	Undamaged Trees			Damaged Trees			Statistics	
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	t-value	p-level
DBH (in)	76	7.10	3.20	11	10.07	4.97	-1.93	0.0401
HT to Base Live Crown (ft)	50	33.02	6.76	8	32.38	5.90	0.28	0.3920
Total Tree Height (ft)	76	48.20	13.23	11	52.36	16.12	-0.82	0.2146
Crown Width (ft)	50	15.02	6.40	8	19.88	8.95	-1.48	0.0872
Tree Volume (cu ft)	76	9.64	10.13	11	22.18	19.68	-2.08	0.0306
Age (yr)	49	26.98	2.27	8	29.00	4.11	-1.36	0.1057
Growth Years 1-5 (mm)	49	14.04	6.81	8	14.10	7.11	-0.02	0.4915
Growth Years 6-10 (mm)	49	22.25	7.79	8	26.32	12.94	-0.86	0.2064
Growth Years 11-15 (mm)	49	21.79	12.22	8	30.20	16.52	-1.38	0.1005
Growth Years 16-20 (mm)	46	17.39	7.88	7	28.07	8.26	-3.21	0.0062
Growth Years 21-25 (mm)	13	16.23	5.46	5	26.37	8.61	-2.45	0.0248
Growth Pith-Thin (mm)	48	82.76	28.00	8	121.62	89.99	-2.26	0.0269
5-7 Year PAI (mm/yr)	30	2.73	1.13	5	3.04	0.99	-0.64	0.2718
Growth Year Thin+1 (mm)	48	2.70	1.64	8	4.04	1.97	-1.83	0.0504
Growth Year Thin+2 (mm)	48	3.45	2.99	8	4.53	2.23	-1.29	0.1142
Growth Year Thin+3 (mm)	48	3.58	1.85	8	4.41	2.55	-0.89	0.1992
Growth Year Thin+4 (mm)	48	2.71	1.55	8	3.11	1.47	-0.70	0.2482
Growth Thin-Bark (mm)	48	12.21	6.17	8	15.55	6.76	-1.31	0.1100
Thin PAI (mm/yr)	48	3.05	1.54	8	3.89	1.69	-1.31	0.1100
Growth Pith-Bark (mm)	48	95.28	33.23	8	137.31	53.12	-2.17	0.0310

Appendix J

Tables of tree parameters of the undamaged and damaged trees in the Deer Camp Area.

Table J.1. Summary of tree parameters of the undamaged and damaged trees growing more than 12 feet from the corridor in the Deer Camp Area.

	Undamaged Trees			Damaged Trees			Statistics	
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	t-value	p-level
DBH (in)	92	9.05	3.44	4	11.35	2.86	-1.56	0.0971
Hgt. to Base Live Crown (ft)	68	38.96	5.16	4	36.00	3.16	1.74	0.0713
Total Height (ft)	68	68.74	8.27	4	66.50	6.86	0.63	0.2827
Crown Classification *	92	2.53	1.05	4	2.00	0.82	1.26	0.1381
Crown Width (ft)	68	17.16	6.35	4	18.50	3.42	-0.71	0.2535
Tree Volume (cu ft)	68	23.45	13.94	4	25.81	13.62	-0.34	0.3769
Age (yr)	65	31.37	3.29	4	30.75	4.35	0.28	0.3989
Growth Years 1-5 (mm)	65	13.64	6.50	4	11.80	6.13	0.58	0.2958
Growth Years 6-10 (mm)	65	23.70	9.83	4	26.61	8.78	-0.64	0.2788
Growth Years 11-15 (mm)	65	25.43	8.99	4	27.99	9.21	-0.54	0.3090
Growth Years 16-20 (mm)	64	19.92	9.00	4	21.94	7.55	-0.51	0.3174
Growth Years 21-25 (mm)	46	16.95	6.38	3	18.41	2.03	-0.98	0.1787
Growth Years 26-30 (mm)	10	16.98	---	1	13.38	---	---	---
Growth Pith-Thin (mm)	65	101.06	29.09	4	108.15	31.03	-0.45	0.3396
Pre-thin PAI (mm/yr)	43	2.96	0.97	4	3.07	0.69	-0.30	0.3895
Growth Year Thin+1 (mm)	67	2.40	1.08	4	2.44	1.08	-0.01	0.4754
Growth Year Thin+2 (mm)	67	3.82	1.50	4	4.16	1.21	-0.54	0.3080
Growth Year Thin+3 (mm)	67	4.33	1.52	4	4.13	1.42	0.27	0.3991
Growth Year Thin+4 (mm)	67	4.14	1.57	4	4.63	1.21	-0.77	0.2423
Grwoth Year Thin+5 (mm)	67	2.27	0.95	4	2.51	0.67	-0.67	0.2697
Growth Thin-Bark (mm)	67	16.72	5.46	4	17.73	4.79	-0.41	0.3523
Post-thin PAI (mm/yr)	67	3.34	3.12	4	3.55	0.96	-0.41	0.3523
Growth Pith-Bark (mm)	65	117.86	32.65	4	126.06	34.58	-0.46	0.3341

* Crowns are classified from 1 (dominant trees) to 4 (suppressed trees).

Table J.2. Summary of tree parameters of the undamaged and damaged trees growing 0-6 feet from the corridor in the Deer Camp Area.

	Undamaged Trees			Damaged Trees			Statistics	
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	t-value	p-level
DBH (in)	79	10.58	3.32	20	12.13	1.59	-3.00	0.0019
Hgt. to Base Live Crown (ft)	67	39.84	4.55	20	42.20	5.46	-1.91	0.0332
Total Height (ft)	67	71.31	6.67	20	73.35	4.38	-1.60	0.0581
Crown Classification *	79	2.13	0.99	20	1.75	0.44	2.52	0.0069
Crown Width (ft)	67	18.73	8.68	20	17.90	4.01	0.60	0.2757
Tree Volume (cu ft)	67	28.33	12.56	20	30.55	9.67	-0.83	0.2045
Age (yr)	65	31.37	2.84	20	31.65	2.32	-0.45	0.3286
Growth Years 1-5 (mm)	65	14.03	7.89	20	14.42	6.80	-0.21	0.4155
Growth Years 6-10 (mm)	65	25.43	8.61	20	25.95	8.29	-0.24	0.4048
Growth Years 11-15 (mm)	65	27.48	7.62	20	30.82	6.69	-1.89	0.0334
Growth Years 16-20 (mm)	65	21.50	7.96	20	23.04	7.21	-0.81	0.2112
Growth Years 21-25 (mm)	46	18.47	6.51	16	18.83	4.64	-0.24	0.4051
Growth Years 26-30 (mm)	7	16.22	3.91	2	18.54	7.77	-0.41	0.3769
Growth Pith-Thin (mm)	65	109.26	24.02	20	166.50	226.57	-1.13	0.1367
Pre-thin PAI (mm/yr)	39	2.99	0.92	20	3.38	0.88	-1.60	0.0588
Growth Year Thin+1 (mm)	66	2.74	1.02	20	2.68	0.97	0.22	0.4123
Growth Year Thin+2 (mm)	66	4.32	1.59	20	4.40	1.43	-0.23	0.4090
Growth Year Thin+3 (mm)	66	4.90	1.62	20	5.08	1.90	-0.38	0.3520
Growth Year Thin+4 (mm)	66	4.53	1.34	20	4.53	1.98	-0.01	0.4954
Grwoth Year Thin+5 (mm)	66	2.57	0.65	20	2.79	0.97	-0.96	0.1730
Growth Thin-Bark (mm)	66	19.06	5.28	20	19.34	6.03	-0.19	0.4266
Thin PAI (mm/yr)	63	3.92	0.94	20	3.87	1.20	0.19	0.4244
Growth Pith-Bark (mm)	65	128.60	27.04	20	135.99	17.72	-1.42	0.0802

* Crowns are classified from 1 (dominant trees) to 4 (suppressed trees).

Table J.3. Summary of tree parameters of the undamaged and damaged trees growing 6-12 feet from the corridor in the Deer Camp Area.

	Undamaged Trees			Damaged Trees			Statistics	
	N	Mean	Std. Dev.	N	Mean	Std. Dev.	t-value	p-level
DBH (in)	59	8.75	3.28	3	13.70	2.74	-3.02	0.0284
Hgt. to Base Live Crown (ft)	44	40.02	4.90	3	35.67	2.08	3.09	0.0107
Total Height (ft)	44	68.11	7.83	3	76.00	6.24	-2.08	0.0646
Crown Width (ft0	44	15.11	4.90	3	23.67	6.03	-2.40	0.0690
Tree Volume (cu ft0	44	21.14	12.62	3	41.70	20.91	-1.68	0.1173
Age (yr)	42	31.12	3.19	3	31.00	3.00	0.01	0.4757
Growth Years 1-5 (mm)	42	14.35	7.34	3	16.88	12.65	-0.34	0.3822
Growth Years 6-10 (mm)	42	23.62	7.88	3	28.99	18.70	-0.49	0.3351
Growth Years 11-15 (mm)	42	23.77	8.57	3	35.12	7.26	-2.58	0.0408
Growth Years 16-20 (mm)	42	18.43	6.44	3	26.33	11.36	-1.19	0.1780
Growth Years 21-25 (mm)	28	15.09	5.24	2	20.11	9.28	-0.76	0.2938
Growth Years 26-30 (mm)	6	14.01	—	0	—	—	—	—
Growth Pith-Thin (mm)	42	97.32	25.69	3	131.11	34.02	-1.69	0.1169
Pre-thin PAI (mm/yr)	25	2.65	1.03	3	3.29	0.83	-1.23	0.1429
Growth Year Thin+1 (mm)	42	2.19	1.11	3	2.53	0.39	-1.19	0.1364
Growth Year Thin+2 (mm)	42	3.52	1.63	3	4.60	0.29	-3.59	0.0007
Growth Year Thin+3 (mm)	42	4.03	1.72	3	5.03	0.53	-2.47	0.0165
Growth Year Thin+4 (mm)	42	4.10	1.98	3	4.99	0.45	-2.22	0.0202
Grwoth Year Thin+5 (mm)	42	2.25	0.85	3	3.00	0.62	-1.97	0.0716
Growth Thin-Bark (mm)	42	15.99	6.24	3	20.15	0.84	-3.87	0.0020
Thin PAI (mm/yr)	42	3.20	1.25	3	4.03	0.17	-3.87	0.0002
Growth Pith-Bark (mm)	42	113.33	28.88	3	151.22	34.87	-1.84	0.1037

VITA

The author was born in 1968 in Seattle, Washington, but lived and received most of his primary education in the east. He completed his secondary education at Franklin High School in Franklin Virginia in 1986. He then completed a B.S. degree in Forestry at North Carolina State University in 1990. From there, he went to Virginia Polytechnic Institute where he completed his Master of Science degree in Industrial Forestry Operation in 1992.

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