Effects of Low-Input Vegetation Management on Pine-Hardwood Mixed Stands in the Northern Piedmont

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ABSTRACT

In an attempt to provide low-cost, low-input alternatives for regenerating pine-hardwood mixtures, this study examined several mechanisms that influence the growth of pine-hardwood stands. The Regeneration Alternatives Study is an ongoing experiment that was designed to gain biological and economical information concerning the growth and yield of loblolly pine and mixed hardwood species. Low-cost herbicide applications (stump treatment, basal stem spray, release, and soil spot release) were used to control competing vegetation during the study.

The four even-aged regeneration treatments applied to loblolly pine and mixed hardwood stands of this study had a significant effect on their growth. Loblolly pine growth increased and mixed hardwood growth decreased as the intensity of herbicide treatment increased for all age classes. In general, loblolly pine was more productive with more intense treatment applications on poorer sites following a growing season harvest. Hardwood species were more productive with less intense treatment applications on higher-quality sites following a dormant season harvest for all age classes. Loblolly pine planting following clearfelling, coupled with a herbicide stump and release treatment (treatment 4), resulted in the highest yields of loblolly pine, the greatest economic returns, and the greatest level of site utilization. However, treatment 4 also resulted in the lowest yield of mixed hardwoods and the lowest level of species richness. Loblolly pine planting following clearfelling, with (treatment 3) and without (treatment 2) a hardwood stump treatment application, resulted in a more even distribution of pines and hardwoods, depending on the treatment. Treatment 3 favored loblolly pine growth, especially following a growing season harvest on poor sites. Treatment 2 favored mixed hardwood growth, especially following a dormant season harvest on good sites. There were no differences between methods of release (basal spray or soil spot herbicide application). Economically, treatments 2 and 3 did not realize a profit on returns.

Pine yields, dbh, and basal area were all significantly greater following a summer season harvest as opposed to pine growth following a winter harvest with the same chemical treatments. The pine growth data indicated that less intense chemical treatments following a summer harvest can achieve the same or greater growth results than more intense chemical treatments following a winter harvest. The results of this study indicate a significant biological and economic tradeoff, depending on the level of hardwood control applied and the time of harvesting.

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CHAPTER 1

INTRODUCTION AND JUSTIFICATION

Pine-hardwood mixtures are a natural component of forested ecosystems in the Southeastern United States. Natural regeneration of pine-hardwood mixtures occurs across the Coastal Plain, Piedmont, and other southern regions of the U.S. Hardwood stems generally occupy from 43 to 66% of the total amount of stems in this cover type (Ruark and Becktold 1989). However, almost 11% of all pine-hardwood stands were originally planted with pine species on previously cleared hardwood sites (Sheffield et al. 1989). Loblolly pine-hardwood cover types are the most common of the pine-hardwood cover types in the South and cover over 14 million acres (Sheffield et al. 1989). The hardwood component of these mixed stands varies from region to region, but some of the dominant hardwood species of the Virginia Piedmont are typically oak species (*Quercus* spp.), blackgum (*Nyssa sylvatica*), red maple (*Acer rubrum*), sweetgum (*Liquidambar styraciflua*), sourwood (*Oxydendron arboreum*), hickory species (*Carya* spp.), and yellow-poplar (*Liriodendron tulipifera*) (Sheffield et al. 1989).

In the Southern U.S., forest succession after agricultural abandonment generally leads to a mix of shade-intolerant pioneer conifer and hardwood species. If pure pine stands develop, either by fire or other major disturbances, they are often high-graded repeatedly and hardwood encroachment occurs (Kays et al. 1988; Steinbeck and Kuers 1996). On poor-quality upland sites, much of the hardwood component generally has low economic value. Despite the low economic value, the hardwood component in many southern pine-hardwood mixtures provides indirect biological and aesthetic benefits. Mixed stands reduce the risk of insect and disease outbreaks, support a more diverse habitat for flora and fauna, and are considered to have more visual appeal to the general public than monocultures (Steinbeck and Kuers 1996).

Past forest practices avoided the management of mixed stands as a desired condition. However, recent trends in public opinion and landowner concerns towards environmental issues have demanded a change in forest management practices. A survey of nonindustrial private landowner opinion leaders showed an interest towards hunting, wildlife, and aesthetics as well as timber (Lentz et al. 1989). Pine-hardwood mixtures offer more management options to private landowners because of the multiple benefits they may provide over monocultures.

Timber production as a source of income is still an objective of private landowners. Unfortunately, many of the lands owned by nonindustrial private landowners are producing at 50% or less of their productivity potential (Dubois et al. 1990, reported by Webb 1990). Underproductivity is due in part to the reluctance private landowners have towards site preparation, which they feel requires intensive mechanical operations (Moorehead and Dangerfield, 1990). Methods of regenerating low-quality hardwood and pine-hardwood forests to more productive and diverse pine-hardwood mixtures have been explored. Traditional methods of regeneration include clearcutting, mechanical or broadcast chemical site preparation, burning, and planting of desired species. Unfortunately, many private landowners can not afford the use of expensive machinery or contract services that these techniques require. Another concern of private landowners is reducing the impact that a silvicultural practice has on the environment. Because of concerns for cost and environmental impact, capital-intensive forest management is less attractive to private landowners than a low-cost, low-input, operation for forest stand regeneration. Furthermore, the successful establishment and sustained regeneration of pine-hardwood mixtures through less intensive management practices will reduce future compounded costs incurred at site preparation, and provide product diversification to a fluctuating timber market (Zedaker et al. 1989).

Low-cost and low-impact site preparation can be achieved through herbicide application (Moorehead and Dangerfield 1990). Herbicides are used to selectively control competing vegetation. Herbicides can be applied through several methods such as aerial, ground mobile, tree injection, and backpack sprayer applications. However, on smaller tracts of land the use of backpack sprayers will keep costs at a minimum when compared to mechanized applications. A study of forestry practices indicated that the average cost of mechanical site preparation averaged $100.74 per acre and chemical site preparation averaged $67.41 per acre (Dubois et al. 1995). Also, no large contractors are necessary. Chemicals can be used to control competing hardwoods with little soil disturbance. They can be used on steeply sloping land where equipment limitations are severe. Some chemical treatments can be applied by the landowner on small acreages where mechanical or aerial methods may be impractical (Dubois 1995).

Backpack sprayers can administer herbicides as a foliar application, a stem or trunk basal spray, or soil-applied spot treatment. The use of backpack sprayers for site preparation reduces the impact on the site as well. There is no soil compaction or rutting from heavy machinery, and soil erosion is diminished due to the remaining debris and treated vegetation on the soil surface. A combination of backpack sprayer site preparation and release can be expected to average $88.60 per acre (Dubois et al. 1995).

There are few studies about the ecological aspects of managing mixed pine-hardwood stands. Changes in species diversity, stand dynamics over time, and inter- and intra-specific competition are all processes that are relatively un-examined for pine-hardwood mixtures. It is imperative that forest managers understand these factors so that landowner objectives can be fully achieved. A greater understanding of the biological mechanisms related to pine-hardwood mixtures will improve predictions of future products and yield, allow for success of specific management goals, and help determine the technology required for better management practices.

In an attempt to provide low-cost, low-input alternatives for regenerating pine-hardwood mixtures, this study examined several biological mechanisms that influence the growth of pine-hardwood stands. The Regeneration Alternatives Study is an ongoing experiment that was designed to gain biological and economic information on the growth and yields of loblolly pine and mixed hardwood species. Several low-cost herbicide applications were used to control competing vegetation during the study.

The overall objective was to examine low-cost, low-impact regeneration methods for growing loblolly pine and mixed hardwood species for private landowners. The study evaluated the effects of site quality, season of harvest (dormant or growing season), and four regeneration treatments on competing vegetation and crop tree growth. The effects of these treatments were examined by comparing responses in the fifth and eighth years of establishment with present thirteenth-year responses. In addition, an analysis was conducted to predict future yield and economic worth through the use of timber models, and to determine the biological and economical tradeoff according to treatment applications.

The specific objectives of this work were: (1) to determine the effects of four even-aged regeneration treatments, site quality, and season of harvest on the growth of planted loblolly pine and naturally regenerated mixed hardwood stands 13 years after establishment; (2) to compare and identify trends in fifth-, eighth-, and thirteenth-year data due to treatment effect, site quality, and season of harvest; (3) to determine the effect site quality, season of harvest, and four regeneration treatments have on hardwood species richness and relative dominance; and (4) to estimate the economic value and yields of the 13-year-old loblolly pine and hardwood stands modeled to future rotation ages.

CHAPTER 2

LITERATURE REVIEW

Mixed pine-hardwood forests are unique in that they are a relatively abundant forest cover type; however, there has been little examination of this resource for stand management. To better understand the role and development of mixed pine-hardwood forests, it was necessary to review how this resource was treated in the past and how it is currently being managed. Thus, new methods of management can be explored and full site utilization can be realized through a better understanding of the processes that favor mixed pine-hardwood growth. The characteristics of mixed pine-hardwood stands were examined first to determine stand composition and how this forest type develops over time. Past analyses of mixed pine-hardwood stands were reviewed to evaluate important findings, and to ascertain the procedures and results associated with previous experiments. Furthermore, site quality, season of harvest, vegetation control, and species competition were examined to determine their effects on hardwood and loblolly growth and yield. This examination allowed for a comparison of effects between past and present data; thus, trends were identified. It was also important to examine species richness, stand models, and economic evaluations to determine the biological and economical costs and benefits of managing mixed pine-hardwood stands. A financial analysis of treatment applications carried to three different rotation ages was performed to provide information to private landowners who seek an alternative to capital-intensive forest regeneration practices.

Characteristics of Mixed Pine-Hardwood Stands

Pine-hardwood forests are a primary source of timber and wildlife habitat in the United States. About 40% of the nation’s commercial forests are in the Southern U.S., and an estimated 15% of these 73.7 million hectares are officially designated as mixed pine-hardwood stands (USDA Forest Service 1988). About 70% of southern forests are owned by private nonindustrial landowners (USDA Forest Service 1988). In the state of Virginia, it is estimated that 80% of the Piedmont forest lands are owned by private landowners (Brown

1986). Approximately 70% of the Virginia Piedmont forests are identified as pine-hardwood forest types (Brown 1986).

Despite the abundance of pine-hardwood mixtures in Virginia, much of this forest land is understocked or comprised of low-quality stems and undesirable hardwood species (Kays et al. 1988). Knight and Mclure (1978) reported that 75% of Virginia Piedmont forests are understocked, with 20% of the stocking in rotten or poorly formed trees. Generally when forest stands are understocked or comprised of mostly cull trees, the standard practice is to clearcut and regenerate the stand (Roach and Gingrich 1968, Mcgee 1982).

In the South, oak species tend to dominate the hardwood component of pine-hardwood forests. Furthermore, oak species account for almost 37% of harvested timber (Sheffield et al. 1989). Other dominant hardwoods include sweetgum, blackgum, yellow poplar, and red maple. The softwood component of pine-hardwood stands in the south is comprised mainly of yellow pines (*Pinus* spp.), the loblolly-shortleaf group, and Virginia (*P. virginiana*) and pitch (*P. rigida* Mill.) pines (Sheffield, et al. 1989). The softwood component of mixed stands tends to be greater than the hardwood component, with a high proportion of softwood volume in the 12-inch and larger dbh classes. Hardwoods are typically centered in the 6, 8, and 10-inch diameter classes. Historically, the larger pines are considered a greater asset from a timber merchandising stand point (Sheffield, et al. 1989).

Across the northern and southern regions of Virginia, it is estimated that 43% of pine-hardwood stands are comprised of sawtimber-sized trees, 28% are poletimber, and 29% are primarily sapling and seedling size (Sheffield et al. 1989).

Sapling and seedling stands are more common in the South. Approximately 11% of all pine-hardwood stands are planted for the softwood component. Regionally, about 55% of pine-hardwood stand volume (ft^3/ac) is softwood and 45% is hardwood; this amount varies. In some southern regions of the U.S., the softwood component can reach 85% (Sheffield et al. 1989).

There are many factors that favor the transition of forested stands to mixed pine-hardwood forests. Partial harvests and natural regeneration in understocked pine stands by hardwood pioneer species commonly lead to pine-hardwood mixtures. High-grading pine stands with a hardwood understory can also create the pine-hardwood type. Natural succession tends to move stands from pine to hardwood in established pine stands. Regionally, pine-hardwood mixtures are considered dynamic and transitory. Through time, stands move into and out of pine-hardwood classification often (Sheffield et al. 1989). Anthropocentric factors such as harvesting and land use practices tend to hasten mixed pine-hardwood succession.

Mixed pine-hardwood stands are considered to favor more diverse wildlife populations. Due to the greater number of different plant species and variations of habitat, mixed pine-hardwood forests are considered more ecologically diverse than monocultures of pine (Smith 1986). Pine plantations have a limited capacity to support large wildlife populations for species such as black bear, deer, turkey, and bobcat; however, mixed stands can support substantial populations of game and non-game species such as turkey, quail, squirrel, and migratory songbirds (Cooper 1989).

Past Analyses of Mixed Stands

In the early 1980's there was a great deal of research examining the silvicultural aspects of growing loblolly pine plantations. Conversely, there was little research effort on the silviculture and management of mixed pine-hardwood stands (Lentz et al. 1989, Smith and Zedaker 1988). Previous data collected on regeneration after harvesting mixed hardwood stands was gathered from Appalachian studies (Wendel and Trimble 1968), central state studies (Sander and Clark 1971), and Southeastern coastal plain studies (Roberts 1960, Knight 1977). These studies were primarily concerned with gathering data on the amount, type, and growth rates of regeneration for different species of hardwoods and pines.

Zedaker et al. (1989) reported that harvest timing and low-input regeneration treatments resulted in significantly different stand conditions. Season of harvest had an impact on both hardwood and pine basal area. Growing season harvests decreased hardwood basal area on chemically treated and untreated plots, resulting in an increase of pine basal area. Dormant season harvests had less of an impact on hardwood basal area. It was concluded that as the level of hardwood control increased, loblolly pine basal area increased and hardwood basal area decreased. These results confirmed earlier work on this study by Newcomer et al.

(1987), where loblolly pine basal area increased as the level of hardwood control increased. Zedaker et al. (1989) concluded that using appropriate combinations of harvest season, herbicide stump treatment at the time of harvesting, and post-planting herbicide release of pine, it is possible to develop forest stands at various compositions of mixed hardwoods and pine species.

A similar study of converting low-quality hardwood stands to pine-hardwood mixtures was reported by McGee (1989). In this study, clearfelling was accomplished through shearing with a feller buncher and injecting residual hardwood stems with herbicide. Loblolly pine was then planted on treated and untreated plots along the Cumberland Plateau and the Western Highland Rim of Tennessee. McGee (1989) concluded that the pine component increased as the intensity of site preparation increased. There are several significant differences in treatment application and experimental design between the McGee (1989) study and the Zedaker et al. (1989) study; however, both studies support the process of developing pine-hardwood mixtures through low-input regeneration methods.

Haywood and Toliver (1989) compared the growth and yield of loblolly pine in pure stands and in pine-hardwood mixtures. The results of this study verified the data reported in Zedaker et al. (1989) that growth and yield increased for loblolly pine as loblolly pine density increased. Loblolly pine growth and yield decreased as hardwood density increased (Haywood and Toliver 1989).

Several recent studies examined effects of chemical release treatments for pine-hardwood mixtures. These studies were mainly concerned with releasing loblolly pine from hardwood competition (Quicke et al. 1996, Fortson et al. 1996). Quicke et al. (1996) measured the effect of herbicide release treatments for planted loblolly pine applied in early spring and in late summer. Imazypyr, in combination with metsulfuron or alone, and glyphosate, in combination with metsulfuron or alone, were applied as broadcast treatments. The late summer treatment was applied in September, and the early spring treatment was applied in May. Since the treatments were applied as a release treatment, some stunting of pine tree height occurred at higher herbicide concentrations. All treatments were effective in controlling hardwood competition. The loblolly pine crop responded with increased diameter, height, basal area, and volume. Fortson et al. (1996) reported that loblolly pine was a widely used species for plantation management. Site preparation prior to the 1970's was primarily from burning or mechanical operations. Recent trends in pine establishment incorporate the use of herbicide applications.

Site Quality and Season of Harvest

Two biological factors that have been studied for their effect on the development of mixed stands are site quality and season of harvest (Kays et al. 1988, Zedaker et al. 1987a). Site quality is generally referred to as a measure of the productive capacity of a given environment (Zedaker et al. 1987b). Site quality in conjunction with climatic factors can determine species composition for a given land region (Zahner and Smalley 1989). Site quality can be measured directly or indirectly. The direct measurement requires the use of site index, where a stand is grown to full stocking levels for a designated period. An indirect approach uses bioassays to determine productivity. A bioassay is simply an indicator species that can grow on specific sites and indicates a level of fertility or physical nature about the site (Zedaker et al. 1987b). Site quality is important for tree growth and can affect interspecific competition. It is generally thought that hardwood species tend to out-compete conifer species on high-quality sites. Zahner and Myers (1984) reported that site quality and site index can affect the productivity of a given site and that different management objectives are appropriate for different site qualities. Trimble (1973) reported that site quality and harvest technique can affect species composition and growth rates. Trimble (1973) indicated that sites with higher site quality generally have increased species richness and growth for hardwood species.

Regeneration methods have been developed and summarized for much of the central, northeastern and southern hardwood regions of the United States (Roach and Gingrich 1968, Merritt 1980, Smith and Linnartz 1980, Smith 1994). The majority of this work involved guidelines for even-aged silviculture and stocking guides. However, there are no guidelines available for management of Piedmont mixed pine-hardwood forest types.

Newcomer et al. (1987) attempted to address this problem through a comprehensive study of the Regeneration Alternatives Study designed by Smith and Zedaker (1982). It was found that increased site quality did have a positive significant effect on hardwood growth. On untreated plots, stem counts were nearly twice as high on good sites as on poor sites (3,068 and 1,759 stems/ha, respectively). Conversely, loblolly pine crown volume was 484.4 m^3/ha on poor sites and 263.3 m^3/ha on good sites. Newcomer et al. (1987) suggested that competition pressure was greatest on good sites, and loblolly pine tends to be out-competed for resources by faster-growing hardwood species.

A case study conducted by Steinbeck and Kuers (1996) on two upland sites in the Georgia Piedmont examined the development of pine-hardwood mixtures 10 years after clearcutting. Generally, case studies have very limited inference space; however, results from this study support results on the effect of site quality in the Regeneration Alternatives Study. It was reported that on better sites, intolerant hardwoods can be expected to be more competitive, whereas on less then average sites, pines are more successful. This confirmed results on site quality reported in the third-year study by Newcomer et al. (1987), in which hardwood growth was higher on good sites and loblolly pine growth was higher on poor sites.

The effect of season of harvest is thought to impact the sprouting potential of many hardwood species. It is known that a growing season harvest will decrease energy stores of the root system, which in turn will decrease sprouting potential and sprout growth the following growing season (Kays et al.1988, Zedaker et al. 1987a, Smith 1986). Newcomer et al. (1987) reported that total hardwood crown volume was significantly greater with a dormant season harvest (14,442 cubic meters per hectare) than with a growing season harvest (7,780 cubic meters per hectare). Crown volume for loblolly pine was inversely related, with crown volume increasing significantly on sites harvested during the growing season. Coincident with harvest season, as the level of herbicide control increased, the number of hardwood stems per hectare decreased. This resulted in greater crown volumes for loblolly pine, with the highest crown volumes consequent to total hardwood control on poor sites after a growing season harvest (Newcomer et al. 1987). Watson (1995) conducted an examination of the eighth-year Regeneration Alternatives data and concluded that mean basal area for loblolly pine on sites following a growing season harvest was 65 ft^2/ac. Mean basal area for pine following a dormant season harvest was 22 ft^2/ac. Loblolly pine basal area also increased as treatment level increased; planted pine only treatment resulted in 21 ft^2/ac;

planted pine and stump treatment resulted in 38 ft^2/ac; and planted pine, stump treatment, and release resulted in 72 ft^2/ac. Conversely, hardwood basal area decreased as treatment level increased; planted pine only resulted in 32 ft^2/ac; planted pine and stump treatment resulted in16 ft^2/ac; and planted pine, stump treatment, and release resulted in 11 ft^2/ac. Total basal area for loblolly pine was highest under a growing season harvest, resulting in a 30% to 54% increase over the dormant season harvest across all treatments. Growing season harvests also had a positive significant effect by increasing dbh and height for loblolly pine (Watson 1995).

Stump Sprout Control

Stump sprouting is the vegetative propagation for regeneration of many upland oaks and hardwood species in Appalachian and Piedmont forests; furthermore, stump sprouts are the major component of natural regeneration for mixed upland oaks following clearfelling (Wendel 1975). Because of the prolific and vigorous growth of stump sprouts following a harvest, this source of hardwood regeneration is a significant competitor to pine seedling establishment. Studies for Appalachian hardwoods reported that up to 42% of stump sprouts following a clearcut will be commercially undesirable species (Loftis 1978 reported in Lewis 1984). Therefore, it is necessary to evaluate the effects of reducing stump sprout competition.

Previous studies on stump sprout growth were conducted by Newton and Knight (1981) and Roach and Gingrich (1968). These studies suggested that stump sprout growth is effected by parent stump diameter and season of harvest. Kays et al. (1988) examined the effects of parent-tree characteristics, age and diameter, harvest season, and site quality on hardwood sprouting frequency. Work related to stump sprouting potential for various hardwood species has been conducted by several other researchers (Wendel 1975, Roth and Hepting 1943, Mcgee and Hooper 1975). The analysis from Kays et al. (1988) confirmed the work of the previously mentioned researchers. Older, larger tree stumps tend to have a reduced frequency of sprouting. Growing season harvests do not necessarily reduce the frequency, but can reduce the growth potential of emerging stump sprouts. Inconclusive results were obtained for the effect of site quality on sprouting frequency (Kays et al. 1988).

From a management perspective, the Kays et al. (1988) study suggests that younger stands less than 80 years old, harvested during the dormant season, have the greatest sprouting potential to regenerate a new stand after harvesting.

After harvesting the Regeneration Alternatives site in February and August 1983, the effect of chemically controlling stump sprout competition was examined. Cut stump treatment effects were examined by Lewis et al. (1984), Kays et al. (1985), and Zedaker et al. (1987a). Lewis et al. (1984) found that herbicide application to cut stumps achieved approximately 90% control of crown volume after the first year of application. Lewis (1984) examined the efficacy of four different herbicides applied as the stump treatment for the study: picloram + 2,4-D (4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid + 2,4-dichlorophenoxy acetic acid as Tordon-101, 5.4%SL), triclopyr (3,5,6-trichloro-2-pyridinyl-oxy-acetic acid as Garlon-4 61.6% EC), dicamba (3,6-dichloro-2-methoxybenzoic acid as Banvel CST 10.6% SL), glyphosate (N-phosphonomethyl-glycine as Roundup 41.0% SL). A growing season harvest in conjunction with herbicide application showed the greatest control of hardwood sprout growth. For all chemicals, the average percent of control was greater then 96% (Lewis, 1984).

Zedaker et al. (1987a) specifically looked at herbicide efficacy by measuring percent control, calculated by using crown area, crown volume, and basal area of pine and hardwood species on treated plots. Overall the study showed a definite potential for reducing undesirable hardwood sprouting. It was reported that the most effective herbicides controlled 90% of hardwood sprouting and killed 60% of hardwood sprouts after two years, averaged over all species (Zedaker et al. 1987a). A cost analysis for the stump treatment revealed that landowners with limited investment expense could control undesirable hardwood sprouting for $15 to $20 per acre (Zedaker et al. 1987a). A study conducted by Smith (1979) in West Virginia resulted in a 30-40% reduction of stump sprouts on herbicide treated plots. Clason (1978) treated cut stumps of hardwood origin in stands of loblolly pine. The study indicated similar findings to Zedaker (1987a) and Smith (1979), in which hardwood competition decreased and loblolly pine growth increased.

Competition Control For Loblolly Pine

The principal management objective for the use of herbicides during site preparation is to control undesirable competing vegetation and promote the growth of crop trees. When the development of pine-hardwood mixtures necessitates the planting of a desired pine species, it is often critical to control competing vegetation several years after planting. This type of treatment is typically called a release operation, where young stands of desirable trees not past the sapling stage are freed from competition (Smith 1986). Herbaceous and woody weed control will improve survival and increase growth of newly planted pines (Quicke et al. 1996, Bacon and Zedaker 1987, Zutter et al. 1986).

Competition control for loblolly pine has been examined in numerous studies. Many of these studies examined the control of herbaceous weeds (Fitzgerald 1979, Nelson et al. 1981, Zutter et al. 1986, Glover et al. 1989). Other studies examined the effect of woody vegetation control on the growth of loblolly pine (Clason 1978, Knowe et al. 1985, Bacon and Zedaker 1987, Fredrickson et al. 1993). Much of this work examined the effect of hardwood competition on loblolly pine yield. From these studies it is generally accepted that vegetation control increases loblolly pine growth. Clason (1990) studied competing vegetation and density effects on loblolly pine growth and development. He reported that growing space availability had a significant impact on loblolly pine growth and that failure to manage interspecific competition can reduce wood yields. Zutter et al. (1994) compared the effects of herbaceous control, woody vegetation control, and their interaction with loblolly pine in a comprehensive region-wide study. This work supported findings of earlier competition work, and discovered that woody and herbaceous control together have an additive effect on loblolly pine growth. Groninger et al. (1994) examined the effects of herbaceous vegetation and stand composition on loblolly pine and red maple growth. This study quantitatively measured growth for specific pine and hardwood components within a mixed pine-hardwood stand. It was reported that relative size of both pine and maple were dependent on stand composition, density, and amount of herbaceous cover present.

Knowe et al. (1985) reported that weed-free loblolly pine seedlings can reach merchantable size several years earlier than those with no weed control. Bacon and Zedaker (1987) found that stem volumes were significantly greater for loblolly pine on herbicide-treated sites. Thus, competition control not only increases pine volume, but stands may reach merchantable size sooner, given the proper conditions. Decreasing the time to reach merchantable size would prove economically attractive to private and industrial landowners alike.

Miller et al. (1995) compared levels of loblolly pine growth for four levels of competition control where maximum potential growth response was analyzed. The four levels of control were: no control, woody control, herbaceous control, and total control. It was concluded that pine trees grown under total control approached maximum growth according to site productivity. The pine growth on total control plots was used to establish a benchmark to compare the productivity or loss of growth of pine on plots with less then total control. Tree diameters, height, stocking, and basal area over an eight-year period were used to determine productivity for 13 different sites. The results of this study confirm previous studies that indicate pine productivity is increased as the amount of competition control is increased. Eight of the 13 sites resulted in higher basal area per acre for eight-year-old pine on herbaceous control plots, compared to that of woody control plots.

Because of the efforts of the previously mentioned scientists and others, it is generally accepted that loblolly pine competes directly with herbaceous vegetation during the seedling stage of development and competes directly with hardwood vegetation during the sapling and mature growth stages, relative to stem density. This knowledge allows forest managers to direct competition control efforts for a given development stage of loblolly pine stands. If the goal is to regenerate pine-hardwood mixtures, the ability to control the level of competition by decreasing or increasing competing stem densities is invaluable. It is also important to understand the impact competition can have on desired tree species.

Plant Diversity

The concept of biodiversity has several meanings and is perceived differently by different people. Diversity in general means a variety, or difference of forms. Biodiversity can simply be regarded as the abundance of different life forms. In forested ecosystems, plant diversity plays a large role due to its relevance to wildlife habitat. Therefore, biodiversity is often scrutinized within managed forestland. Public and regulatory agencies seek to conserve and re-establish diversity in forested ecosystems. Unfortunately, the ability to reliably measure plant diversity in quantitative terms is questionable. Yet biodiversity is growing in public concern with regard to silvicultural and chemical management (Zedaker 1991). Due to the diverse nature of mixed pine-hardwood stands, this forest type has been the subject of several diversity studies.

Watson (1995) worked with data collected from 10 x 10 m plots in the eighth year Regeneration Alternatives study. Site quality, season of harvest, and four levels of control were examined for their effect on species richness and diversity. It was concluded that site quality had a significant effect on species richness on sites harvested during the dormant season. Woody plant richness reached a maximum of eight species per plot on good sites and five species per plot on poor sites. On growing season-harvested plots, there was no significant difference in species richness due to site quality. Woody plant richness was five species on good sites and four species on poor sites, where white oak (*Q. alba*) site index (base age 50) was greater than 65 feet in height on good sites and less than 65 feet on poor sites. A Shannon Diversity Index was computed for treatment effect for woody vegetation control and season of harvest. Watson (1995) reported that as the vegetation treatment levels increased in intensity, the value of the Shannon Index decreased; no woody vegetation control resulted in a Shannon Diversity Index of 1.31, and total woody vegetation control resulted in an Shannon Index of 0.52. A dormant season harvest had a greater diversity value than a growing season harvest, 1.17 and 0.72, respectively ($p\text{-value} < 0.05$).

The effects of chemical site preparation on plant diversity have been examined by other researchers for different studies (Boyd et al. 1994, McMinn 1992, Neary et al. 1990, Swindel et al. 1984, Zutter and Zedaker 1988). Neary et al. (1990) reported that repeated annual herbicide applications can strongly reduce plant diversity; however, there were insufficient data to determine the long-term effects that normal herbicide use has on plant diversity. McMinn (1992) found that the Shannon Diversity Index following a dormant season harvest was generally lower than after a growing season harvest. This finding contradicts the Watson (1995) report. Watson (1995) remarked on this contradiction, stating that the higher measures of diversity on dormant season harvest sites for the Regeneration Alternatives study were the result of a higher proportion of woody competition basal area.

O'Connell et al. (1992) measured the effects of chemical and mechanical site preparation on vegetative diversity. Results indicated no statistical differences in diversity the first two years after application between mechanical and chemical applications, but diversity was higher on the mechanical treatments in the fourth year. Species richness increased for both treatments over time. It was reported that either preparation technique can have an important effect on the redeveloping plant community.

Often wildlife habitat is correlated to species diversity (Brooks et al. 1992, Miller and Witt 1990, Miller and Chapman 1995). Miller and Witt (1990) reported that herbicides used for vegetation management are not as detrimental to wildlife habitat as was previously assumed. Wildlife habitat was evaluated by the response of wildlife food plants to site preparation treatments. It is suggested that chemical treatments tend to shift species composition from woody plant dominance to a mix of woody plant and forbs. In most cases this shift resulted in higher habitat values for small mammal and bird populations (Miller and Witt 1990). Typically, wildlife habitat is dependent on temporal and spatial conditions for a given environment. It is also dependent on plant species composition. Thus, the true impact herbicides have on plant diversity during site preparation is dependent on multiple edaphic characteristics inherent in a given site (Mannon et al. 1994).

Economics of Mixed Pine-Hardwood Management

The economic returns for hardwood competition control in mixed pine-hardwood stands are a direct concern for forest managers and private landowners who wish to grow merchantable timber. Private landowners are often concerned with optimizing returns, not maximizing production. For forest landowners, this means settling for an adequately stocked stand when the cost of getting full stocking is too high (Willet and Baker 1990). Several studies have examined the economic aspect of mixed pine-hardwood management (Dangerfield and Edwards 1994, Hepp 1989, Franklin 1989, Miller et al. 1994).

Hepp (1989) examined four levels of regeneration treatments following clearfelling on six plots. The treatments and their costs per acre were: (1) natural regeneration, $0; (2) pine planting, $53; (3) inject residuals, plant pine, $101; and (4) chop, burn, plant pine, $171. Investment returns were dependent on cultural practices used for site preparation and future prices for hardwood and pine sawtimber. The Soil Expectation Value (SEV) was used as the financial criterion to measure financial returns. Injection and planted pine treatments yielded the highest value of $130 SEV/acre at stand age 40; chop, burn, and plant was the second highest value at $110 SEV/acre at stand age 45. The greatest increase of pine sawtimber volume was on the chop and burn sites, followed by the injection of residual competitors. However, the intensive chop and burn treatment could only be justified when pine sawtimber stumpage prices exceeded $80/Mbf; lower pine stumpage prices suggested the inject and plant pine treatment was better. The inject and plant pine treatment also allowed for a greater component of hardwood volume to be harvested. Hepp (1989) concluded that the introduction of a loblolly pine component boosts volume yield and net economic returns relative to a pure hardwood culture. Growth and yield for this study was predicted through the use of two computer programs: YIELDplus: Timber Yield Forecasting and Planning Tool (Hepp, 1989), and HDWD (Burkhart and Sprinz, 1984).

Miller et al. (1994) used data collected from the Competition Omission Monitoring Project (COMP) to project yields and derived economic outcomes for loblolly pine under varying levels of hardwood and herbaceous competition. Land Expectation Value (LEV) was used to calculate economic outcomes. Projected pine yields were estimated using the North Carolina State University Managed Pine Plantation Growth and Yield Simulator, version 3.2, created by Hafley and Smith (1987). The inputs for the model were stand age, pine and hardwood basal area, hardwood growth form, stocking, and height age curves. Hardwood volume was only estimated as pulpwood. Pine volumes were estimated for sawtimber, chip-and-saw, and pulpwood.

Traditionally, silviculturalists have viewed mixed pine-hardwood stands as prime candidates for conversion to pure pine. Thus, there has been little work conducted on models that can estimate growth and yield for mixed stands. However, recent interest in managing mixed stands has initiated several researchers to study this problem. Lloyd (1989) examined some of the early research used to develop growth and yield forecasting models for mixed pine-hardwood stands. Several precepts on pine-hardwood ecology and growth were used as guidelines for developing early models. Species in mixed stands were grouped for stand-level statistical analyses based on a combination of shade tolerance, site quality occurrence, and similarity of growth patterns. Modeling was simplified by building separate sets of height growth curves for specific species groupings and their site types. Models incorporated the concept that growing space used by one species or species group in a mixed stand is not available for other species or species groups. Lastly, periodic growth estimates from both stand table projection and rotation-length prediction models should be the same when site quality, basal area, and stand age are equal.

Smith and Hafley (1987) based their simulation program on independently developed planted pine and natural hardwood models to predict the development of such stands. Smith et al. (1989) believed the percent of hardwood basal area that develops in pine plantations established after harvesting a natural mixed hardwood stand without intensive site preparation does not remain constant. In fact, they report that the percent of hardwood basal area will first decrease and then increase as the age of the stand increases (Smith et al. 1989).

Growth and yield models are fairly common and accurate for loblolly pine stands. Often these models are developed regionally to benefit from local data. One such model for the Virginia Piedmont is PTAEDA2V, developed by Burkhart and Amateis (1993). Generally, growth and yield models are used to predict volume and yield into the future and these predicted yields are then analyzed for economic value. The difficulty in economic analyses for pine-hardwood mixtures is determining growth and yield for the hardwood component of a mixed stand. ECONHDWD is limited in only predicting hardwood volume as pulpwood.

Bowling et al. (1988) developed a multispecies growth model for Appalachian hardwoods. This model uses species groups and product classes within species groups to predict growth and yield of mixed Appalachian hardwood stands. The simulator uses a basal area growth equation to predict future stand basal area, which is an important part of the model. Volume estimates are obtained by relating tree height to dbh midpoint classes. One drawback to the model is that it was designed for thinned mixed hardwood stands. However, it may be possible to gain insights from this model to predict heights and volumes of hardwood components in mixed pine-hardwood stands.

The computer program HDWD, later renamed ECONHDWD, can assess the economic consequences of vegetation management for unthinned loblolly pine stands (Burkhart and Sprinz, 1984). Stand and stock tables can be produced for the pine component of a stand, as well as estimates for the volume of hardwood pulpwood. In addition, an economic analysis can be calculated that includes net and gross harvest value, net present value, internal rate of return, and the marginal rates of return (Sprinz et al. 1991). It is important to note that ECONHDWD assumes that the ratio of hardwood basal area remains constant over time. This assumption contradicts data reported by Smith et al. (1989).

Summary

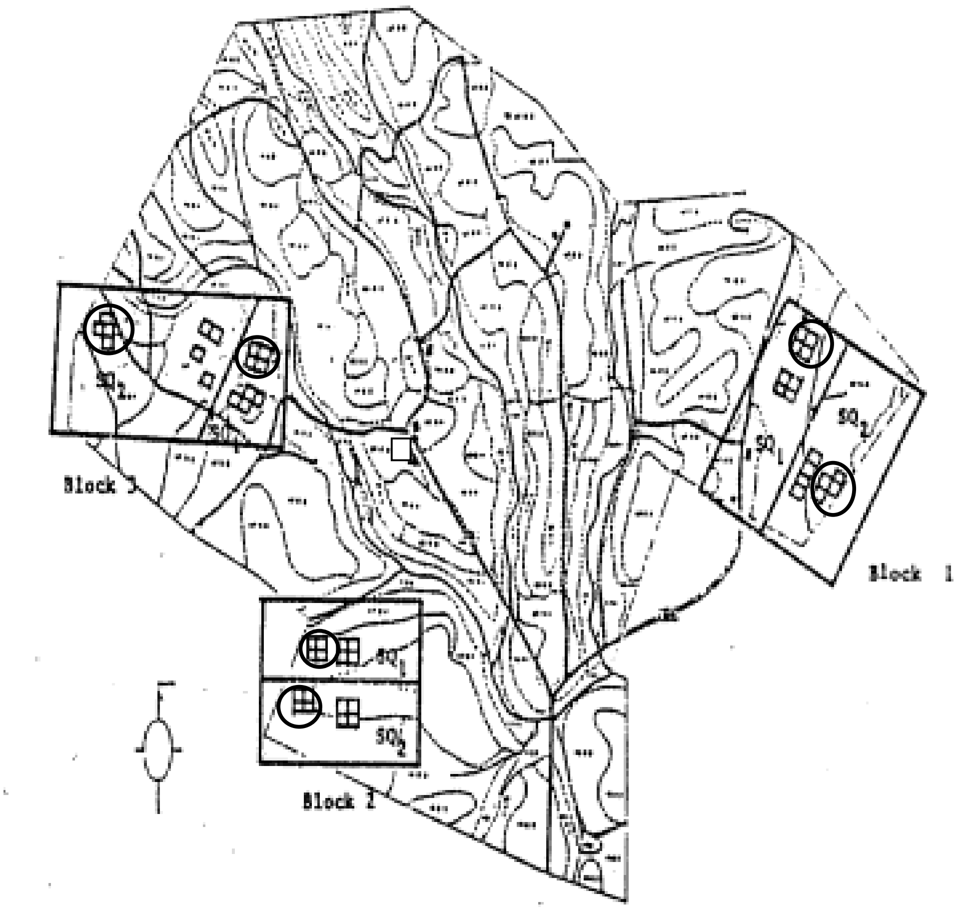
A review of the past literature on mixed pine-hardwood stands has shown a strong emphasis on the pine component of these forest types. Few studies have considered both hardwood and pine species as being equally important in their analyses. This Regeneration Alternatives study hopes to provide new and insightful information on the development of both pine and hardwood species in mixed pine-hardwood stands. The effects of four regeneration treatments, site quality, and harvesting season on the growth of mixtures of planted loblolly pine and naturally regenerated hardwoods were examined to provide a measure of how these stands holistically respond to edaphic and anthropocentric factors. The low-input methods used to prepare and establish the mixed stands can be used as an incentive for management alternatives for private as well as industrial and governmental landowners. The Regeneration Alternatives study is one of the few studies that has accumulated response data over a period of time. Therefore it was necessary to identify any trends or changes associated with fifth-, eighth-, and thirteenth-year data. This will allow for effective long-term management strategies and flexibility for a transitional resource. Mixed pine-hardwood stands are essentially an unmanaged resource. Predicting future growth and yield and providing an economic comparison of costs and benefits will help determine the feasibility of utilizing this resource. Lastly, responsible silviculture examines the ecological impact of its cultural practices on stand composition and structure. Thus, species richness and relative dominance were measured to determine the effect four regeneration treatments had on stand composition.

CHAPTER 3

MATERIALS, METHODS, AND ANALYSIS

The Regeneration Alternatives Study was established on the Reynolds Homestead Forest Resources Research Center in the upper Piedmont of Patrick County, Virginia, in 1982 (Figure 1). The soils are mostly eroded Ultisols developed from granitic and metamorphic bedrock. Slopes for the study site range from 2 to 36%, with 6 to 10% being common (Newcomer 1986). Summer temperatures range from 102^o to 35^oF, with an average of 77^oF. Winter temperatures range from 73^o to 16^oF, with an average of 50^oF. The frost-free period is between mid-April and the end of October. Yearly average rainfall is 49 inches, with a monthly average of 4 inches (Crockett 1972, reported in Lewis 1984).

Stand quality on plots prior to harvest was considered poor (Lewis 1984). Stand age ranged from 50 to 80 years across plots, and site indices were less than 65 feet for white oak (base age 50) on poor sites and greater than 65 feet for white oak (base age 50) on good sites (Newcomer 1986). Pre-harvest stand composition on most sites was comprised of chestnut oak (*Q. prinus*), scarlet oak (*Q. coccinea*), white oak, red maple, sourwood, yellow-poplar, and Virginia pine (Newcomer 1986, Lewis 1984). Oak species comprised about 59% of the pre-harvest stand basal area on poor sites, and 34% of the basal area on good sites (Lewis 1984). Yellow-poplar, white oak, red maple, and northern red oak dominated the good sites, and chestnut oak, scarlet oak, and sourwood dominated the poor sites.



Key

○ = Winter Harvests

SQ1 = Good Site Quality

SQ2 = Poor Site Quality

☐ = Research Center

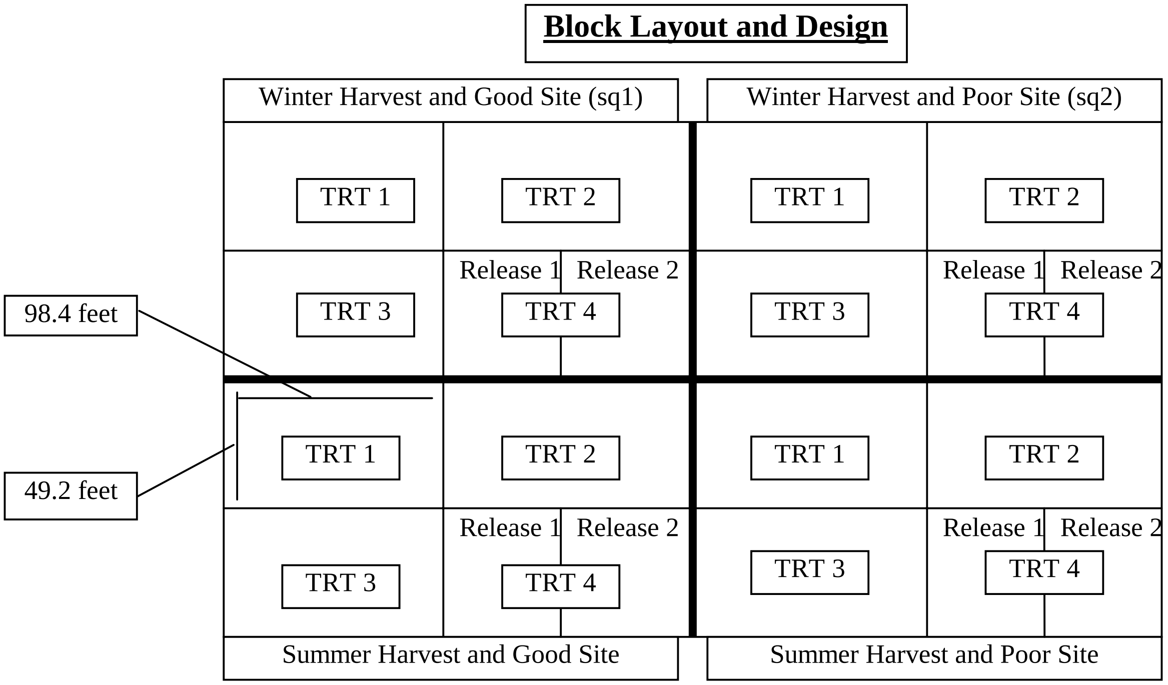


Figure 1. Overview of Reynolds Homestead Plot Layout, Patrick County, Critz Virginia

Study Design

The study was set up as a split-split-plot design, with three blocks. Whole plots represented site quality (good and poor) and split plots were used for season of harvest. Split plots were randomly assigned a dormant or growing season clearfelling and whole-tree yarding (Figure 1). The dormant season harvest was completed between 17 February and 29 April 1983. The growing season harvest was accomplished between 6 June and 11 August 1983. Each harvest split-plot was divided into four split-split plots used for regeneration treatments. The original experimental plan delineated 48 98.4 x 98.4-ft treatment plots where half of the plot was planted with pine seedlings prior to harvesting, and the other half was planted after harvesting, a third split plot. Due to harvesting damage and unacceptable survival, the pre-planted portion of the study was dropped from the experiment. Thus, only 98.4 x 49.2-ft post-harvesting plots were utilized for the fifth, eighth, and thirteenth-year experiments. Each group of four split-split plots randomly received one of four treatments. The treatments were as follows:

Treatment 1: clearcut (stems greater than 1 inch felled within 6 inches of ground level), whole-tree yarded, natural regeneration.

Treatment 2: clearcut, whole-tree yarded, planted 1-0 loblolly seedlings at 6.6 x 6.6-ft spacing.

Treatment 3: clearcut, whole-tree yarded, planted 1-0 loblolly seedlings at 6.6 x 6.6-ft spacing, undiluted herbicide applied to cambial region of hardwood stumps immediately after felling.

Treatment 4: clearcut, whole-tree yarded, planted 1-0 loblolly seedlings at 6.6 x 6.6-ft spacing, undiluted herbicide applied to cambial region of hardwood stumps immediately after felling, and basal bark spray or soil-applied herbicide pine release treatment in March 1985 (Newcomer 1986, Lewis 1984).

Herbicide Application

Hardwood stumps in treatments 3 and 4 were treated at an average rate of 0.85 oz. of herbicide per square foot of basal area. Individual hardwood stumps were treated with one of the following herbicide applications: picloram + 2,4-D (4-amino-3,5,6-trichloro-2-

pyridinecarboxylic acid + 2,4 dichlorophenoxy acetic acid as Tordon-101, 5.4%SL); triclopyr (3,5,6-trichloro-2-pyridinyl-oxy-acetic acid as Garlon-4 61.6% EC); dicamba (3,6-dichloro-2-methoxybenzoic acid as Banvel CST 10.6% SL); glyphosate (N-phosphonomethyl-glycine as Roundup 41.0% SL); or hexazinone (3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1H,3H)-dione) as Velpar L 25% SL). Effects due to treatments 3 and 4 represent an average response of hardwood reduction for all herbicide applications (Zedaker et al. 1987a).

The release for treatment 4 consisted of two different operations:

1. basal application of 4% triclopyr (ester) as Garlon-4 61.6% EC, diluted with diesel fuel and administered with a backpack sprayer: All stems within 3.28 ft of loblolly pine seedlings received herbicide application to the bottom 6-8 inches of stems until runoff. An average of 3.7 gallons of triclopyr and 8.8 gallons of diesel fuel were used for release treatments per acre.
2. spot application: A soil-active herbicide was used to release loblolly stems, applied as 50% hexazinone as Velpar L 25% SL in water with a spotgun. The mixture was applied in a 3.28-ft radius around each loblolly pine seedling. Approximately 1 gallon of hexazinone was used for release treatments per acre (Zedaker 1989). The data for the different herbicide release plots were combined and represent the mean response due to release treatments.

Sampling Methods

Fifth-Year Measurements

The fifth-year sampling was conducted during the summer of 1989. This sampling design established sampling plots located approximately in the center of each 98.4 x 49.2-ft treatment plot. One 32.8 x 32.8-ft sampling plot was located per treatment plot for treatments 1, 2, and 3. Two 32.8 x 32.8-ft sampling plots were located in treatment 4 plots to measure response data due to different herbicide release treatments. The data collected and the units of measurement were as follows:

1. A complete census was taken for species, dbh, and height for all hardwood and conifer stems 2 inches dbh and greater per 32.8 x 32.8-ft sampling plot, across all treatment plots.

2. Stem diameter was measured with a diameter tape in inches to the nearest 0.1 inch. Stem height was measured in feet to the nearest 0.1 foot.
3. Two randomly selected nested plots 6.6 ft by 6.6 ft were located within the 32.8 x 32.8-ft sample plots. Woody species height and crown diameter were collected for all hardwood and conifer rootstocks measuring less than 2 inches dbh.

Eighth-Year Measurements

The eighth-year sampling was conducted during the summer of 1992. This sampling design was the same as the fifth-year design with two exceptions. The 6.6 x 6.6-ft randomly selected nested plots were not measured, and tree heights were measured in feet to the nearest 0.1 foot.

Thirteenth-Year Measurements

The thirteenth-year sampling survey was measured during the summer and fall of 1996. A complete census of all 98.4 x 49.2-ft treatments plots was conducted to collect data on woody species richness, dbh by 1-inch diameter classes, and tree heights for loblolly pine stems 2 inches dbh and greater. Tree heights and dbh for hardwood stems 2 inches dbh and greater were measured on 16 randomly selected subplots to attain a hardwood height estimator. All tree heights were measured to the nearest 0.1 foot with a Halgolf Vertex Hypsometer (a digital height measuring device). The Hypsometer was calibrated through a sampling of trees and with a height pole (meter increments) prior to data collection, and found to be extremely accurate +/- 0.1 foot. Stem diameters were measured with a diameter tape (i.e., 4.5-inch to 5.4-inch stems were recorded as the 5-inch diameter class).

A circular subplot (radius = 14.7 ft) was located in the center of each 98.6 x 49.2-ft treatment plot for measuring smaller woody stems. All hardwood and conifer stems in the 1-inch diameter class were tallied for species richness. All woody root stocks less than 1 inch in diameter class were measured for percent cover by species. Percent cover of the subplot was visually estimated using a pre-arcsine transformed cover class scale.

Tree heights for hardwood species were measured on sites within 16 randomly selected subplots. Three to five dominant and co-dominant hardwood stems were selected depending on plot location (good or poor) per subplot.

Procedures for Thirteenth-Year Study

A plot layout design and location system was established during the original study. Plot corners were marked with 3-inch diameter pvc poles approximately 3 to 6 feet tall, depending on block location, for all 48 plots. Each plot corner pole had a locator tag attached with wire. This tag had the plot number inscribed on it. All plots were surveyed for condition, and plot corners were re-located with flagging. A forest fire had damaged four treatment plots in block 1 prior to the fifth-year analysis. These four plots were on a poor site and were harvested during the growing season. The four plots were dropped from the fifth-, eighth-, and thirteenth-year experimental analysis because they no longer represented effects due to treatments. Plots missing the corner tag were re-tagged upon confirmation of identity. Plot location and treatment applied were confirmed with the tag number and treatment code plot sheets developed from the initial studies. Actual plot corner numbers corresponded to plot numbers on the bottom right corners of the plot layout sheets.

Data Analysis

The data were separated into two groups (loblolly pine and mixed hardwoods) and and all stems greater than 2 inches dbh were statistically tested for effects due to site quality, season of harvest, and treatment effects. Loblolly pine stand parameters tested were mean height, mean dbh, basal area per acre, and cubic feet per acre. Hardwood stand parameters tested were mean dbh, basal area per acre, cubic feet per acre, and species richness. Hardwood height was not tested for effects due to treatments because of the variable height growth for different tree species. This analysis was done using split-split plot analysis of variance (ANOVA) through the use of the statistical computer program SAS for the fifth-, eighth-, and thirteenth-year data. Duncan’s Multiple Range Test was used to separate treatment means for all variables. An alpha level of 0.05 was used to test significance for all hypotheses. Where significant interactions occurred, a Least Significant Difference (LSD) analysis was applied to separate the means using SAS.

SAS was also used to test the significance of the difference between the chemical release treatment means using the *t* statistic. Treatment 4.1 (release 1) was the triclopyr basal spray, and 4.2 (release 2) was the hexazinone spot treatment.

Simple linear regression was used to determine an estimator of hardwood tree heights for a given diameter class. Estimated tree heights were considered for three species groups: yellow poplar, red maple and non-oak species, and oak species. Yellow poplar was the only species where tree heights were significantly different than the other species groups ($P > t = 0.006$). Therefore, two estimators of tree height were used, one for yellow poplar ($Ht_{yp} = 18.51 + ((-20.10) * (1/dbh_{yp}))$) and the base formula for all other species ($Ht = 13.43 + ((-12.62) * (1/dbh))$).

Stem volume for the thirteenth-year data was calculated separately for each species group: loblolly pine, yellow poplar, and other species. These species groups were determined by their relative dominance, applicable volume equations, and growth and form characteristics. Stem volume for loblolly pine was calculated in cubic foot volume for stems 3 inches and greater using a volume equation developed by Amateis and Burkhart (1987). This equation was regionally developed for loblolly pine plantations in the South and measures total stem volume outside the bark. The equation is as follows: $V_{tob} = a_o + a_1 D^2 H$, where V_{tob} = total volume outside bark (ft^3), D = dbh (in), H = total tree height (ft), $a_o = 0.18658$, and $a_1 = 0.00250$; $R^2 = 0.98$. The stem volume equation for yellow-poplar was developed for the Southern Appalachian region by Knoebel et al. (1984). Total stem volume outside the bark was measured for stems 3 inches and greater.   The equation is as follows: $V_{tob} = b_o + b_1 D^2 H$, where V_{tob} = total volume outside bark (ft^3), D = dbh (in), H = total tree height (ft), $b_o = 0.010309$, and $b_1 = 0.002399$; $R^2 = 0.98$. Total stem volume for all other species was measured for stems 3 inches and greater using the constant form factor equation: $V = b_1 D^2 H$, where V = total volume outside bark (ft^3), D = dbh (in), H = total tree height (ft), and $b_1 = 0.00250$, a coefficient developed for Southeastern hardwood species used by the Southeastern Forest Experiment Station, USDA Forest Service.

Hardwood species dominance was determined by the relative basal area per species per acre. Species richness was determined by the number of species per treatment across whole plots and sub-plots, for the fifth-, eighth-, and thirteenth-year data.

Hypothesis Testing

When preparing hypotheses to test for the Regeneration Alternatives Study, it was necessary to first develop an error mean square table depicting sources of error and effects interaction for a split-split-plot design. The table follows:

Table 1. EMS Table.

Source	**Degrees of Freedom**	
Block	2	
Site	1	
site*block / error a	2	
Total		**5**
Season	1	
seas*site	1	
seas*site*blk / error b	4	
Total		**6**
treatment	3	
trt*seas	3	
trt*site	3	
trt*seas*site	3	
trt*seas*site*blk / error c	24	
Total		**36**
D.F. =	**47**	

Whole Plot Effects

Site quality was the whole or main effect tested.

H_o: site quality does not have a significant effect on mean loblolly pine tree heights, dbh, basal area per acre, and cubic feet per acre.

H_o: site quality does not have a significant effect on mean hardwood dbh, basal area per acre, cubic feet per acre, and species richness.

H_o: there was no significant interaction between site quality and treatment effect.

Split-Plot Effects

Season of harvest was the split-plot effect tested.

H_o: season of harvest does not have a significant effect on mean loblolly pine tree heights, dbh, basal area per acre, and cubic feet per acre.

H_o: season of harvest does not have a significant effect on mean hardwood dbh, basal area per acre, cubic feet per acre, and species richness.

H_o: there was no significant interaction between season of harvest and treatment effect.

Split-Split-Plot Effects

The four regeneration treatments were the split-split-plots effects tested;

H_o: mean tree heights, dbh, basal area per acre, and cubic feet per acre for loblolly pine across treatments are equal.

H_o: mean tree dbh, basal area per acre, cubic feet per acre, and species richness for hardwood stems across treatments are equal.

Modeling Growth and Yield

Currently there are no growth and yield models specifically designed to estimate future growth parameters for mixed pine-hardwood stands. There are models such as G-Hat and NETWIGS that estimate hardwood species volumes; however, these models are for pure hardwood stands. There are also several models that estimate loblolly pine volumes taking into account hardwood competition, such as PTAEDA2 and ECONHDWD.

ECONHDWD will estimate both loblolly pine and hardwood volumes, and was the program used for the economic value and yield analysis of this study. However, the program has several limitations. It cannot estimate a specific species of hardwood volume; it groups all hardwood species into one category, hardwood competition. Furthermore, the program will only estimate hardwood volume as pulpwood, not sawtimber. The program accounts for the hardwood component as percent of the stand originally as hardwood, and can modify loblolly pine volumes according to percent hardwood control.

ECONHDWD can provide an economic analysis for stand projections. The program takes into account the costs for site preparation, hardwood control, and harvesting, and compares these costs to revenues gained from harvested timber. Costs are compounded, and subtracted from the gross value at the time of harvest. Due to limitations of the program, only the 13-year data was used for the input parameters of the model.

Several assumptions were made to estimate future volumes and economic value for both loblolly pine and hardwood yields. The control plots of hardwood stand basal area were converted to represent the percent of hardwoods originally occupying the site. The amount of hardwood basal area controlled by treatments 2, 3, and 4 was converted to percentages based on the 13-year-old basal area of the loblolly pine component. Due to program limitations, the percent of hardwood basal area controlled remained the same throughout the rotation length. Economic returns and yields were evaluated for treatments 2, 3, and 4 on a per-acre basis. Stands were carried to rotation ages 25, 30 and 35. ECONHDWD was limited to estimating up to a 40-year rotation.

Timber Mart-South was used to define average pine sawtimber ($/Mbf) and pine/hardwood pulp prices ($/cord). Table 2 reports the summary of standing timber, 1996 yearly averages.

Table 2. 1996 yearly average per dollar (quarters 1, 2, 3, 4) for sawtimber and pulpwood.

	Pine Sawtimber (MBF)	Chip-n-Saw (cd)	Pulpwood (cd)	
			Pine	Hdwd
Western VA	143	41.68	15.33	6.48
Eastern VA	223	47.46	15.65	6.31
Average	183	44.57	15.49	6.41

(Timber Mart-South 1996)

The values from the above table were used as parameters for the economic modeling options within ECONHDWD. Costs for the economic model were based on a study by Dubois et al. (1995). This study examined the cost trends for forestry practices in the South. The average costs for cultural practices in 1994 were as follows: less than intensive site preparation, $69.65/acre; planting, $39.01/acre; and competition reduction (herbicide control), $67.41/acre. Zedaker et al. (1989) reported that the costs of initial stump treatment for the Regeneration Alternatives Study averaged between $10 and $15 per acre, and that the additional release treatment averaged between $45 and $55 per acre. A planting cost of $39/acre and herbicide control cost of $25/acre were used for defining costs for ECONHDWD on treatment 3; the herbicide control cost was $67/acre for treatment 4. There was no cost incurred for the application of treatment 2. Site preparation costs were not incurred due to the nature of the harvest. Seedling costs were negated for Figure 10, assuming that certain agencies will provide seedlings for private land reforestation at no cost. The cost of application and hourly wages were deferred against the assumed revenue gained from the harvested timber. Default price and cost parameters of ECONHDWD were used for the remaining input variables (Table 9). Their use in the model was to provide a baseline reference to monetarily evaluate regeneration methods.

A further analysis using ECONHDWD was generated to evaluate stand volumes and values whereby site index was manipulated to approximate the effect of season of harvest. It was assumed that since season of harvest had a significant effect on pine growth, this effect could be estimated by adjusting the site index parameter within the model. Several iterations were run modeling the existing 13-year-old stand (Table 10). These iterations were not projected to a future rotation age. They were carried to a 13-year-old stand within ECONHDWD to see what site index levels estimated volumes approximated actual stand volumes. It was determined that SI 80 best approximated a summer harvest and SI 55 represented a winter harvest for loblolly pine growth (Appendix AB). Additional cost parameters for planting ($40.00) and land taxes ($2.00) were added to the model to get more robust financial results. Recognizing the program’s limitations, an estimation for hardwood pulpwood was carried to a 30-year rotation age for comparison with pine results (Table 11).

CHAPTER 4
RESULTS AND DISCUSSION

The Effects of Three Regeneration Treatments on Loblolly Pine

The treatments for the planted loblolly stands were examined for their effects on mean tree height, mean tree diameter at breast height, and basal area per acre for their corresponding age classes. Main treatment effects were significant for all loblolly pine measurements except for 13-year pine heights (Tables 3A, 3B,and 3C), where tree heights showed no significant effect due to hardwood control. There were significant season x treatment interactions for fifth-, eighth-, and thirteenth-year diameters at breast height; fifth- and eighth-year basal area per acre; and fifth-year heights (Tables 3A, 3B,and 3C). Where significant interactions between season x treatment occurred, an LSD test was applied to those mean values for winter and summer seasons, respectively (Tables 3A, 3B, and 3C). There were no significant interactions between site and treatment.

Due to significant interactions, season of harvest had an effect on the level of treatment effect for loblolly pine dbh, basal area per acre, and tree height (Tables 3A, 3B, and 3C). This interaction seemed more significant for younger stand ages and for less intense chemical treatments. The interaction occurred primarily due to the additive effects of season of harvest in conjunction with chemical treatments used to control hardwood growth. A summer season harvest showed to have an increased positive effect in conjunction with treatment effects for loblolly pine growth.

Data from Table 3A indicate that for all age classes, mean dbh values for season of harvest were significantly different for treatments 2 and 3, but not treatment 4. Furthermore, for all age classes, mean dbh for treatments 2 and 3 (summer harvest) are not significantly different then the mean dbh for treatment 4 (winter harvest). The 13-year-old pine stands showed no significant interaction for basal area; however, there were significant differences due to the separate effects of harvest season and treatment.

Table 3A. Summary of mean dbh responses of loblolly pine to regeneration treatments 5, 8, and 13 years following clearfelling for the Regeneration Alternatives Study.

Stand Age	Treatment	Season of Harvest Winter	 Summer	Mean Values
		--------------- dbh (in) ---------------		
5	2	0.8 d	2.4 bc	1.5 A
	3	1.9 c	2.8 ba	2.3 B
	4	2.7 ba	3.1 a	2.9 C
8	2	1.3 d	3.3 b	2.2 A
	3	2.3 c	3.8 ba	3.0 B
	4	4.0 ba	4.3 a	4.1 C
13	2	2.3 d	5.0 bc	3.6 A
	3	4.5 c	5.4 ba	4.9 B
	4	5.5 ba	5.9 a	5.6 B

ABC means followed by the same letter are not significant at the 0.05 level.

abcd means followed by the same letter are not significant at the 0.05 level.

Treatment 1: clearcut (stems greater than 1 inch felled within 6 inches of ground level), whole-tree yarded, natural regeneration.

Treatment 2: clearcut, whole-tree yarded, planted 1-0 loblolly seedlings at 6.6 x 6.6 ft spacing.

Treatment 3: clearcut, whole-tree yarded, planted 1-0 loblolly seedlings at 6.6 x 6.6 ft spacing, undiluted herbicide applied to cambial region of hardwood stumps immediately after felling.

Treatment 4: clearcut, whole-tree yarded, planted 1-0 loblolly seedlings at 6.6 x 6.6 ft spacing, undiluted herbicide applied to cambial region of hardwood stumps immediately after felling, basal bark spray or soil-applied herbicide.

Table 3B. **Summary of mean basal area per acre (ft^2/ac) responses of loblolly pine to regeneration treatments 5, 8, and 13 years following clearfelling for the Regeneration Alternatives Study.**

Stand Age	Treatment	Season of Harvest		Mean Pine Values	Mean Total Pine and Hardwood
		Winter	Summer		
		---------------------- BA/ac ----------------------			
5	2	0.64 c	16.1 b	7.7 A	13.8
	3	3.48 c	33.7 a	17.2 B	21.2
	4	9.50 b	21.8 a	15.1 B	16.1
8	2	4.45 c	37.3 b	19.4 A	51.7
	3	10.32 c	66.4 a	35.9 B	52.0
	4	26.3 b	45.1 a	35.3 B	40.6
13	2	14.6 c*	76.0 b*	40.6 A	99.3
	3	27.6 c*	114.7 a*	67.9 B	107.7
	4	96.4 b*	123.4 a*	113.5 C	141.1

Mean total basal area for pine and hardwood was not tested for significance

* Indicates no significant interaction between season and treatment.

ABC means followed by the same letter are not significant at the 0.05 level.

abcd means followed by the same letter are not significant at the 0.05 level.

Treatment 1: clearcut (stems greater than 1 inch felled within 6 inches of ground level), whole-tree yarded, natural regeneration.

Treatment 2: clearcut, whole-tree yarded, planted 1-0 loblolly seedlings at 6.6 x 6.6 ft spacing.

Treatment 3: clearcut, whole-tree yarded, planted 1-0 loblolly seedlings at 6.6 x 6.6 ft spacing, undiluted herbicide applied to cambial region of hardwood stumps immediately after felling.

Treatment 4: clearcut, whole-tree yarded, planted 1-0 loblolly seedlings at 6.6 x 6.6 ft spacing, undiluted herbicide applied to cambial region of hardwood stumps immediately after felling, basal bark spray or soil-applied herbicide.

Table 3C. Summary of mean height responses of loblolly pine to regeneration treatments 5, 8, and 13 years following clearfelling for the Regeneration Alternatives Study.

Stand Age	Treatment	Season of Harvest		Mean Values
		Winter	Summer	
		------------- Height (ft) -------------		
5	2	6.8 b	16.6 a	11.3 A
	3	15.3 a	16.4 a	15.8 B
	4	17.2 a	18.8 a	17.9 B
8	2	.	.	17.5 A
	3	.	.	23.0 B
	4	.	.	27.9 C
13	2	.	.	33.5 A
	3	.	.	37.1 A
	4	.	.	40.2 A

. Indicates no significant interaction between season and treatment.

ABC means followed by the same letter are not significant at the 0.05 level.

abcd means followed by the same letter are not significant at the 0.05 level.

Treatment 1:	clearcut (stems greater than 1 inch felled within 6 inches of ground level), whole-tree yarded, natural regeneration.
Treatment 2:	clearcut, whole-tree yarded, planted 1-0 loblolly seedlings at 6.6 x 6.6 ft spacing.
Treatment 3:	clearcut, whole-tree yarded, planted 1-0 loblolly seedlings at 6.6 x 6.6 ft spacing, undiluted herbicide applied to cambial region of hardwood stumps immediately after felling.
Treatment 4:	clearcut, whole-tree yarded, planted 1-0 loblolly seedlings at 6.6 x 6.6 ft spacing, undiluted herbicide applied to cambial region of hardwood stumps immediately after felling, basal bark spray or soil-applied herbicide.

As mentioned in the Methods and Materials section, treatment 4 consisted of two different chemical release treatments. Treatment 4.1 was the triclopyr basal spray and treatment 4.2 was the hexazinone spot treatment. It was hypothesized that the two release treatments would have the same effect on pine growth; therefore, the effects were averaged across study plots and the treatment was considered a single treatment (treatment 4). The hypothesis that release treatments did not differ significantly for mean effects was tested using the *t* statistic for 13-year pine dbh and height data. The test results confirmed the hypothesis that the release treatment mean values for pine did not significantly differ (Appendix AA).

Five-year-old loblolly pine stands show that treatment 3, herbicide application to competing hardwood stumps following clearfelling, had a significant positive effect on pine height, dbh, and basal area (Tables 3A, 3B, and 3C). This significant positive effect for treatment 3 was also present for 8- and 13-year-old loblolly stands. Treatment 4 had the same application as treatment 3, followed by a herbicide release treatment of basal bark spray or soil application 3 years after planting. Tables 3A, 3B, and 3C show that treatment 4 did have a significant effect on tree height, dbh, and basal area on all three stand ages except tree height for year 13 data. The greatest effect was indicated by year 13 data, where treatment 4 incurred a 64% increase of basal area over treatment 2 and a 40% increase over treatment 3. Loblolly pine data from Tables 3A, 3B, and 3C suggest several trends relevant to 5-, 8-, and 13-year-old stands.

In comparing the loblolly pine data for treatment 2 (planted pine-no hardwood control), there was a 60% increase of basal area (BA/ac) from the fifth year to the eighth year and a 52% increase in BA/ac from the eighth year to the thirteenth year. For treatment 3, there was a 52% increase in BA/ac from the fifth year to the eighth year and a 47% increase from the eighth year to the thirteenth year. For treatment 4, there was a 57% increase of BA/ac from the fifth year to the eighth year and a 67% increase from the eighth year to the thirteenth year. Treatments 2 and 3 indicated a decreasing percentage of loblolly pine basal area as the stand progressed towards year 13, whereas treatment 4 indicated an increasing percentage of basal area. The magnitude of the decreasing or increasing basal area for pine growth corresponds to the level of treatment applied. Treatments 3 and 4 indicate that competition control through herbicide treatments had a positive effect on pine growth, and this is analogous with Zutter et al. (1994), where woody and herbaceous chemical control had an additive effect on loblolly pine growth.

Figure 2 depicts an inverse relationship between an increasing loblolly pine basal area and a decreasing mixed hardwood basal area for all age classes as hardwood competition control increases by treatment. It is important to note the effect treatment 4 had increasing the margin between loblolly pine basal area and hardwood basal area as the stand progressed from the fifth year to the thirteenth year. The 5- and 8-year-old stands indicate that pine basal area was greatest for treatment 3. This may be a delayed reaction to the release treatment application following three years after stand establishment. The benefits of the release treatment were not fully realized until sometime after the eighth year and during the thirteenth year. This corresponds to the Miller et al. (1995) study, which cited highest basal area per acre of pine for 8 of 13 sites following eighth-year measurements.

Smith and Hafley (1987) and Smith et al. (1989) indicated that the percentage of hardwood basal area in pine plantations would increase over time. Data from Figure 2 confirm this assumption. For all three treatments, the percentage of hardwood basal area increased as the stand age increased. This data differs from the assumption made for ECONHDWD, where the percentage of hardwood basal area remains unchanged over time.

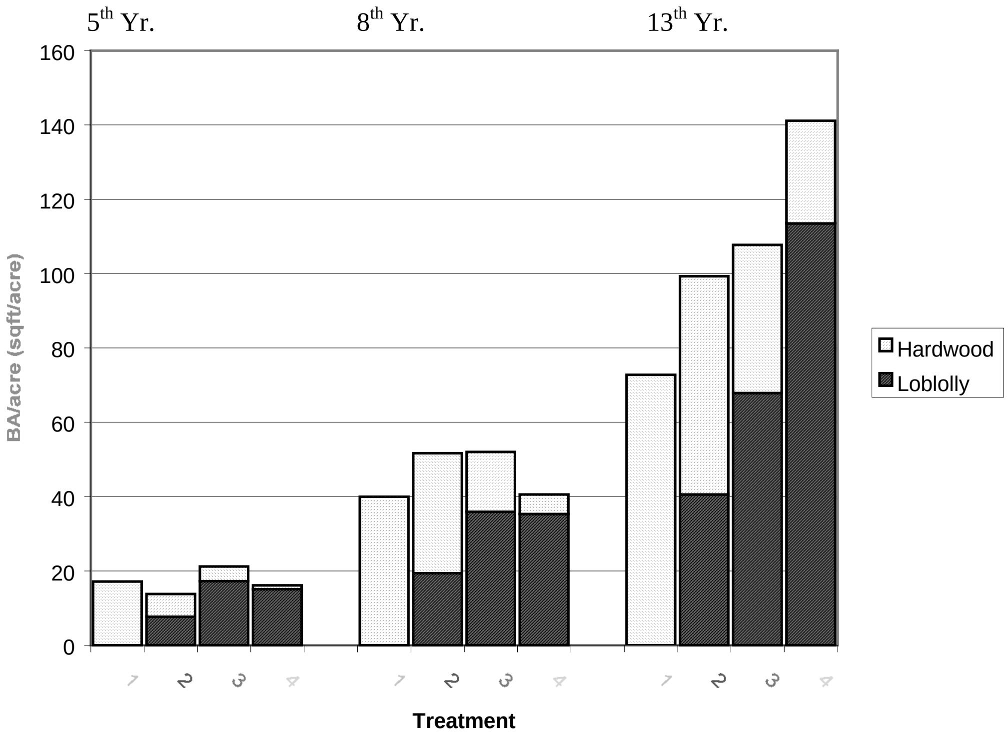


Figure 2. Combined hardwood and pine basal area for fifth, eighth, and thirteenth-year data for the Regeneration Alternatives Study.

The data from Figure 3 show that as hardwood control increases, loblolly pine yield increases and mixed hardwood yield decreases. These results are expected and have been substantiated through previously cited studies. However, there is one aspect of the inverse relationship that needs to be addressed. Determining yield from an existing stand is one method of providing information on the growth of actually harvested trees. Production is the overall growth of the entire stand, deposited on existing trees whether harvested or not (Smith 1986). Due to the difficulty and ambiguity of measuring forest production as a function of overall stand growth and site utilization, stand yield (ft^3/ac) is a measurement often used to derive how well a stand is growing or utilizing a site to its fullest potential. If in a very general sense yield is equated to productivity, Figure 3 indicates that control plots (natural mixed hardwood regeneration) are 51% less productive then loblolly pines under treatment 4 application. There is essentially no difference in total productivity between treatments 2 and 3 other than the relative dominance of pines versus hardwoods. It appears that treatment 4 allows for the highest production and site utilization. Webb (1990) addressed productivity in his studies and suggested many unmanaged private forest landholdings are producing at 50% or less of their productivity potential.

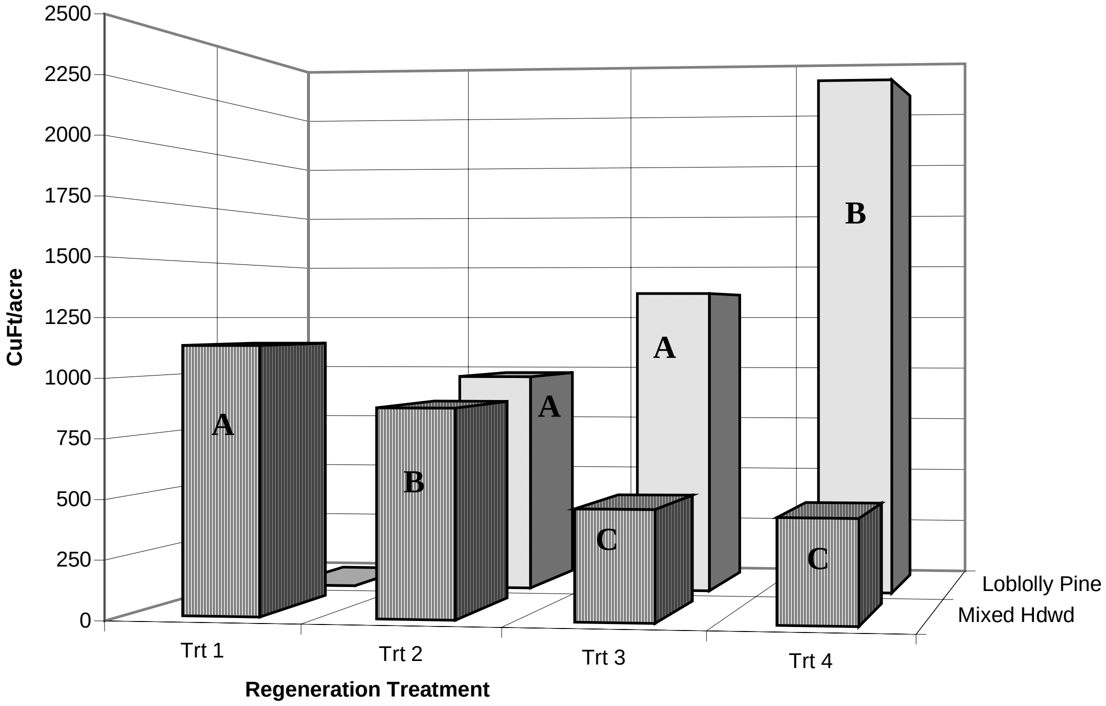


Figure 3. **Thirteen-year-old loblolly pine and mixed hardwood yields per treatment for the Regeneration Alternatives Study. ABC means followed by the same letter are not significant at the 0.05 level.**

The Effects of Four Regeneration Treatments on Mixed Hardwoods

The impacts of the four regeneration treatments on the mixed hardwood stands were examined for their effects on mean hardwood diameter at breast height, basal area per acre, and species richness for their corresponding age classes (Table 4). The effect of the four treatments on hardwood cubic feet per acre was also examined (Figure 3).

Table 4. Summary of mean stand parameter responses of mixed hardwoods to regeneration treatments 5, 8, and 13 years following clearfelling for the Regeneration Alternatives Study.

Stand Age	Treatment	dbh (in)	BA/Acre	Species Richness*
5	1	2.3 A	17.1 A	N/A
	2	2.2 AB	6.1 B	N/A
	3	1.8 AB	4.0 B	N/A
	4	1.4 B	1.0 B	N/A
8	1	2.2 A	40.0 A	6 A
	2	2.1 AB	32.3 A	5 A
	3	2.1 AB	16.1 B	5 A
	4	2.0 B	5.3 C	4 A
13	1	2.7 A	72.8 A	11 A
	2	2.6 A	58.7 B	11 A
	3	2.5 B	39.8 C	10 A
	4	2.4 B	27.6 D	8 B

ABC means followed by the same letter are not significant at the 0.05 level.
N/A = insufficient or unavailable data
Differing sampling methods for species richness were used for the 8th and 13th years.
* Number of species per X/area plot

Mean hardwood diameter shows a significant decreasing effect when comparing treatment 1 (control stand-natural regeneration) with treatments 3 and 4 for all age classes. Hardwood basal area showed a significant decrease due to treatments 3 and 4 as well. In the fifth year there was a 64% decrease in BA/ac from treatment 1 to treatment 2, a 76% decrease from treatment 1 to treatment 3, and a 94% decrease from treatment 1 to treatment 4. In the eighth year there was a 19% decrease in BA/ac from treatment 1 to treatment 2, a 60% decrease from treatment 1 to treatment 3, and an 87% decrease from treatment 1 to treatment 4. In the thirteenth year there was a 19% decrease in BA/ac from treatment 1 to treatment 2, a 45% decrease from treatment 1 to treatment 3, and a 62% decrease from treatment 1 to treatment 4. As the stand progressed from the fifth year to the thirteenth year, the effect of hardwood control for treatments 3 and 4 decreased with time. Without hardwood control, the control treatment BA/ac increased 57% from the fifth year to the eighth year, and 45% from the eighth year to the thirteenth year.

The Effects of Site Quality and Season of Harvest on Loblolly Pine Growth

Site quality for the planted loblolly stands was examined for the effect on mean tree height, mean tree diameter at breast height, basal area per acre, and cubic feet per acre for their corresponding age classes (Table 5). It is important to note that the alpha level used to test the significance of this hypothesis was 0.05. The data from the table indicate that site quality did not have a significant effect on the measured parameters. However, a positive growth trend for diameter at breast height, basal area per acre, and cubic feet per acre across all age classes on poor sites is evident. These findings correspond with the Newcomer et al. (1987) and Steinbeck and Kuers (1996) studies that suggested hardwood species tend to be more competitive on good sites and loblolly pine is more successful on poorer-quality sites.

Season of harvest for the planted loblolly stands was examined for the effect on mean tree height, mean tree diameter at breast height, basal area per acre, and cubic feet per acre for their corresponding age classes (Table 6). Contrary to the effect of site quality, summer harvesting had a significant positive effect for all measured pine parameters across all age classes. This effect was well documented in Kayes et al. (1988), Zedaker et al. (1987a), and Smith (1986) whereby harvesting during the growing season detrimentally impacts the sprouting potential of many hardwood species reducing the competition, and promoting increased loblolly pine growth. Basal area for pine during the fifth year indicates that loblolly pine survivorship was significantly greater following a growing season harvest. An interesting point to note was that summer harvesting in conjunction with the application of herbicide treatments for 13-year-old stands resulted in loblolly pine occupying 73% of basal area and mixed hardwoods occupying 27%. Conversely, a winter harvest resulted in loblolly pine occupying only 44% of basal area and mixed hardwoods occupying 56%.

Table 5. Summary of mean stand parameter responses of loblolly pine to site quality 5, 8, and 13 years following clearfelling for the Regeneration Alternatives Study.

Stand Age	Quality	Height (ft)	dbh (in)	BA/Ac	Ft^3/Ac
5	Poor	15.7 A	2.3 A	13 A	N/A
	Good	14.4 A	2.1 A	13 A	N/A
8	Poor	23.1 A	3.2 A	31 A	N/A
	Good	22.6 A	3.0 A	29 A	N/A
13	Poor	36.0 A	4.9 A	80 A	1562 A
	Good	37.7 A	4.5 A	69 A	1547 A

ABC means followed by the same letter are not significant at the 0.05 level.
N/A = insufficient or unavailable data.

Table 6. Summary of mean stand parameter responses of loblolly pine to season of harvest 5, 8, and 13 years following clearfelling for the Regeneration Alternatives Study.

Stand Age	Harvest	Height (ft)	dbh (in)	BA/ac	Ft^3/ac
5	Summer	17.3 A	2.7 A	24 A	N/A
	Winter	13.1 B	1.8 B	5 B	N/A
8	Summer	26.7 A	3.8 A	50 A	N/A
	Winter	19.6 B	2.5 B	14 B	N/A
13	Summer	44.1 A	5.4 A	110 A	2394 A
	Winter	30.9 B	4.1 B	44 B	854 B

ABC means followed by the same letter are not significant at the 0.05 level.
N/A = insufficient or unavailable data

Harvesting during the growing season also resulted in the consistent significant positive effect on loblolly pine height, dbh, and basal area per acre for all ages (Tables 3A, 3B, and 5). It is generally thought that tree density or basal area per acre does not have a significant effect on tree height (Smith 1986). However the data from Table 6 show that reduced hardwood competition due to a growing season harvest can have a positive effect on height growth. A growing season harvest also had a remarkable effect on loblolly pine cubic feet per acre, a 64% increase over winter harvesting. This confirms the Knowe et al. (1985) study that reported loblolly pine seedlings free from competition can reach merchantable size at an earlier age.

Data from Table 3B also indicate that the season of harvest can equate to hardwood control approximating a chemical treatment application. For the 13-year age class, treatment 2 mean pine dbh and basal area for a summer harvest significantly exceeds treatment 3 winter harvests. Furthermore, Treatment 3 mean pine dbh and basal area for a summer harvest meets or exceeds the treatment 4 effects for a winter harvest. These results are consistent throughout the three age classes measured.

The Effects of Site Quality and Season of Harvest on Mixed Hardwood Growth

The impact of site quality on the mixed hardwood stands was examined for its effect on mean hardwood diameter at breast height, basal area per acre, cubic feet per acre, and species richness for the corresponding age classes (Table 7). Site quality did not have a significant effect on hardwood dbh or basal area per acre, but it did have a significant effect on cubic foot yield. However, hardwood basal area is greater on good sites for all age classes. The absence of significance may be a function of testing the hypothesis at an alpha level of 0.05, or possibly a confounding of the test due to the ecological requirements of different hardwood species comprising the mixed hardwood component. Zahner and Myers (1984), Newcomer et al. (1987), and Steinbeck and Kuers (1996) reported that site quality and site index can affect hardwood productivity, and it is apparent from the hardwood yield data that yield, being a function of potential site productivity, was significantly greater on higher-quality sites.

Table 7. Summary of mean stand parameter responses of mixed hardwoods to site quality 5, 8, and 13 years following clearfelling for the Regeneration Alternatives Study.

Stand Age	Quality	dbh (in)	BA/Ac	Species Richness	Ft^3/Ac
5	Poor	2.0A	6A	N/A	N/A
	Good	2.0A	8A	N/A	N/A
8	Poor	2.1A	21A	4A	N/A
	Good	2.1A	26A	6A	N/A
13	Poor	2.5A	44A	8A	646A
	Good	2.6A	54A	12B	846B

ABC means followed by the same letter are not significant at the 0.05 level.
N/A = insufficient or unavailable data.

The impact of season of harvest on the mixed hardwood stands was examined for its effect on mean hardwood diameter at breast height, basal area per acre, cubic feet per acre, and species richness for their corresponding age classes (Table 8). Season of harvest did not have a significant effect on hardwood diameter at breast height or basal area per acre, but it did have a significant effect on cubic foot yield. However, examining Table 8 will reveal a consistent decrease in hardwood basal area for all age classes for a growing season harvest. When examining the significant effects season of harvest had on loblolly pine growth (Table 6), it is unclear why the hardwood stands were not significantly affected as expected. Confounding of the test may have occurred due to the different species responses to the time of harvest. Newcomer et al. (1987) reported that total hardwood crown volume was significantly greater following a dormant season harvest. These results correspond with the significant positive effect a winter harvest had on the 13-year hardwood cubic foot yield. If yield is an estimation of the true net value of production for a given stand, it must be assumed that a dormant season harvest will result in higher hardwood productivity within the inference space of this study.

Table 8. Summary of mean stand parameter responses of mixed hardwoods to season of harvest 5, 8, and 13 years following clearfelling for the Regeneration Alternatives Study.

Stand Age	Harvest	dbh (in)	BA/ac	Species Richness	Ft^3/ac
5	Summer	1.6 A	4 A	N/A	N/A
	Winter	2.2 A	10 A	N/A	N/A
8	Summer	2.0 A	17 A	5 A	N/A
	Winter	2.2 A	28 A	6 A	N/A
13	Summer	2.5 A	42 A	10 A	641 A
	Winter	2.6 A	56 A	10 A	840 B

ABC means followed by the same letter are not significant at the 0.05 level.
N/A = insufficient or unavailable data.
Differing sampling methods for species richness were used for the 8th and 13th years.

The Effects of Four Regeneration Treatments on Species Richness and Dominance

The effects of the four regeneration treatments on species richness and species dominance were measured for the 8- and 13-year data to identify changes in stand composition. Changes in species richness and relative dominance can be correlated to an effect on species diversity. The four regeneration treatments did not have a significant effect on hardwood species richness for the 8-year data. However, the treatments did have a significant effect for the 13-year treatment 4 application. Mean species richness dropped from 11 on the control plots to 8 for the treatment 4 plots. Similar results were reported by Watson (1995), who stated that cut-stump treatments coupled with release resulted in a significant negative effect on species richness and Shannon diversity.

Figures 4 and 5 indicate that 8-year mixed hardwood relative dominance decreases for all species following a treatment 4 application except for Virginia pine. Virginia pine was considered woody competition towards the planted loblolly pines and was therefore included with the mixed hardwood data. Virginia pine reacted in a similar manner to the loblolly pine per treatment. As expected, hardwood dominance decreased as hardwood competition control increased. However, not all hardwood species reacted to treatments in the same manner, as was indicated by white oak, black cherry (*Prunus serotina*), and yellow-poplar. The 13-year data followed the same general pattern as the 8-year data with a few notable exceptions. Yellow-poplar dominance increased over 15% following treatment 4 from the eighth year to the thirteenth year and exceeded the increase of dominance on natural regeneration plots.

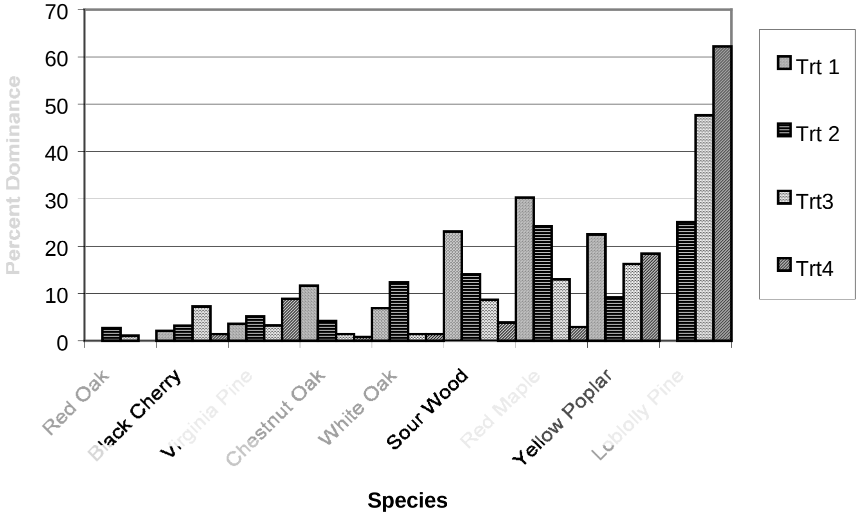


Figure 4. Eighth-year relative dominance per species (stems/acre) for four regeneration treatments for the Regeneration Alternatives Study.

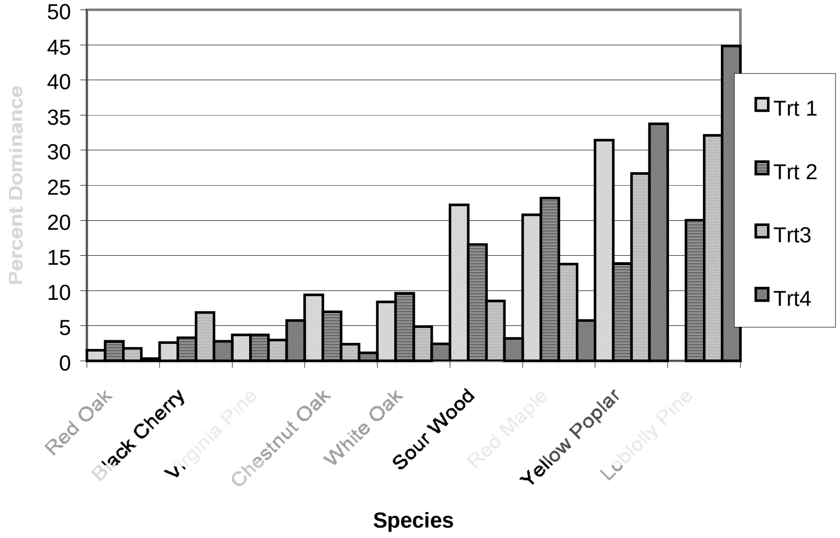


Figure 5. Thirteenth-year relative dominance per species (stems/acre) for four regeneration treatments for the Regeneration Alternatives Study.

It is suspected that yellow-poplar was resistant to one or more of the herbicides used during application and has had a positive increase in growth due to decreasing competition from red maple and sourwood. Yellow-poplar and loblolly pine combined constituted 59% and 79% of the total stand composition for treatments 3 and 4, respectively, whereas red maple and sourwood combined constituted 54% and 40% of the total stand composition for treatments 1 and 2, respectively.

The results from Figures 4 and 5 suggest that increasing hardwood control allocated the greatest relative dominance to loblolly pine and yellow-poplar. For this study, less intense treatment applications provide for a more even distribution of relative dominance per species. These findings are in agreement with Swindel et al. (1984), who reported that species richness and diversity generally decrease as hardwood competition control increases. However, even on natural regeneration plots, a select few species (red maple, sourwood, and yellow-poplar) tended to dominate the site and less competitive species (oaks, black cherry, and Virginia pine) made up a small percent of the residual composition.

The Effects of Site Quality and Season of Harvest on Species Richness and Dominance

Site quality did not have a significant effect on 8-year species richness; however, site quality did have a significant effect on 13-year species richness (Table 7). Trimble (1973) reported that species composition and hardwood regeneration can be affected by differences in site quality. Species richness was significantly greater for mixed hardwoods on good sites (greater then 65 ft for white oak, base age 50). The difference of significance between the 8- and 13-year results may be due to the level of sampling conducted for each year of study. The 13-year study conducted a complete species census for the entire treatment plot of 15 x 30 m; the 8-year study only measured 10 x 10 m plots.

There were several unexpected results of species dominance due to site quality (Figures 6 and 7). Chestnut oak and sourwood had higher dominance on poorer quality sites, and the 8-year loblolly pine dominance was unaffected. Generally it was thought that hardwood competition growth increased due to higher quality sites (Newcomer et al. 1987 and Steinbeck and Kuers 1996), and this is indicated by the results from Figures 6 and 7. However, it is apparent that site quality can affect specific hardwood species differently, as indicated by the responses of chestnut oak and sourwood. The effect of site quality on species dominance showed a similar trend for the 8- and 13-year data with one exception. Loblolly pine dominance increased almost 10% on poorer sites for the 13-year data.

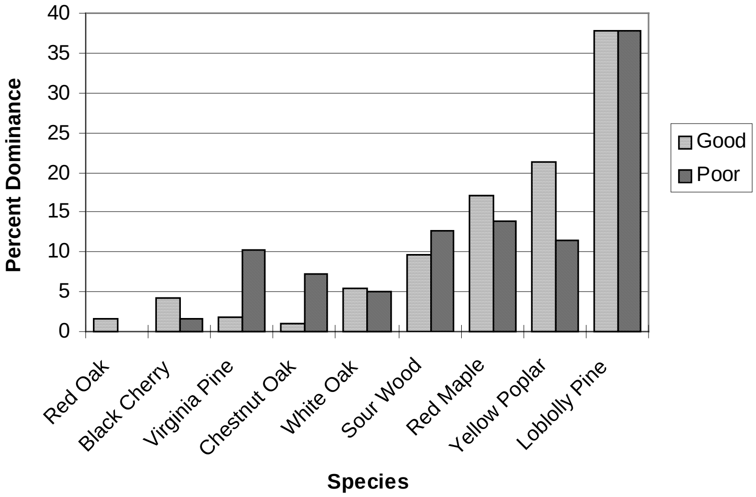


Figure 6. Species dominance (stems/acre) per site quality for 8-year data for the Regeneration Alternatives Study.

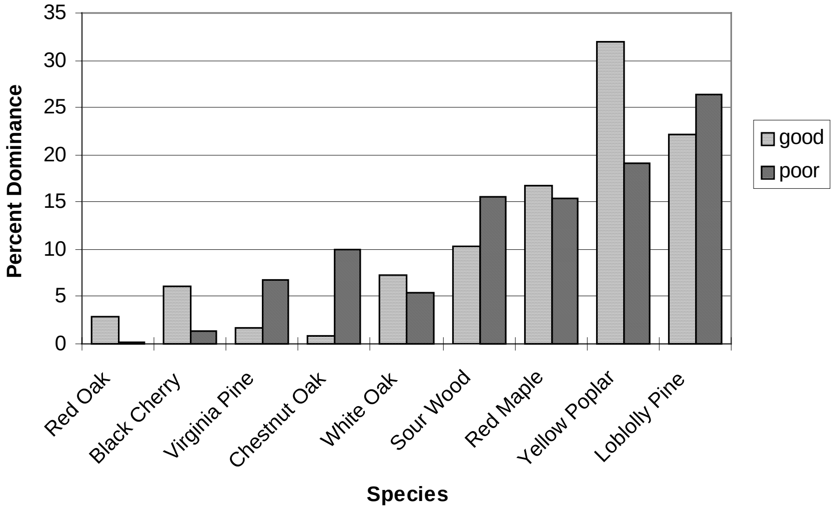


Figure 7. Species dominance (stems/acre) per site quality for 13-year data for the Regeneration Alternatives Study.

Season of harvest was expected to have a significant effect on species richness due to the significant negative effects it had on mixed hardwood basal area per acre, dbh, and yield. Surprisingly, season of harvest had no significant effect on hardwood species richness (Table 8). Watson (1995) reported that season of harvest coupled with herbicide treatments produced a significant negative effect on hardwood species richness and diversity. Season of harvest alone did not have an effect on species richness or diversity.

Season of harvest may not have affected species richness; however, it did have an effect on species dominance (Figures 8 and 9). The 8- and 13-year data suggest that all hardwood species except for white oak decreased in relative dominance and pine species dominance increased due to a growing season harvest. These results were expected and correlate well with results from Zedaker et al. (1987a), Newcomer et al. (1987), Kays et al. (1988), and Watson (1995), whereby hardwood competition was significantly decreased due to a growing season harvest.

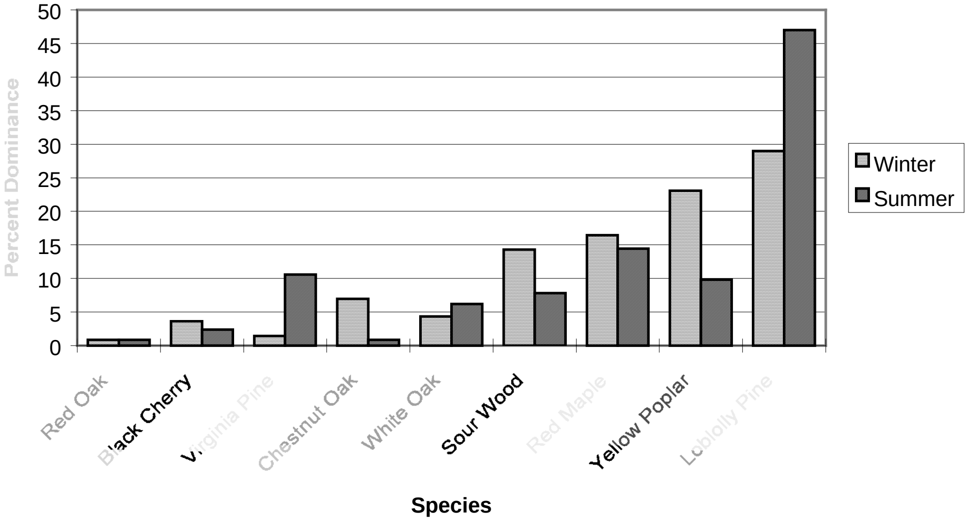


Figure 8. Species dominance (stems/acre) per season of harvest for 8-year data for the Regeneration Alternatives Study.

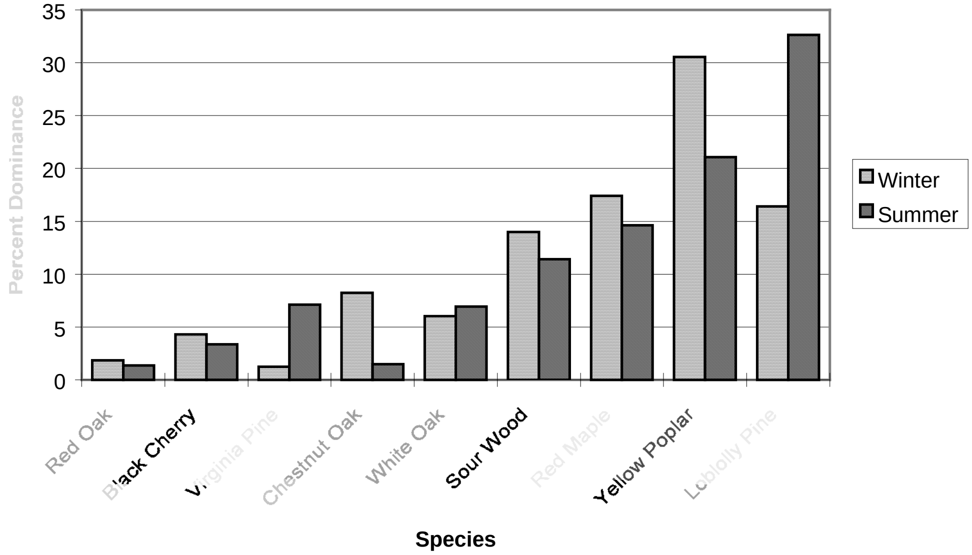


Figure 9. Species dominance (stems/acre) per season of harvest for 13-year data for the Regeneration Alternatives Study.

Modeling Summary of the Regeneration Treatments

Economic and yield values were modeled for treatments 2, 3, and 4, estimated to the harvest rotation ages of 25, 30, and 35 per treatment (Table 9). ECOHDWD automatically combined the values generated from harvesting loblolly pine pulpwood and sawlogs and hardwood pulpwood. The greatest economic return of $59.56/acre was estimated for treatment 4, carried to a 30-year rotation (Figure 10). However, there was a greater rate of return (R.O.I) on hardwood control for the same treatment carried to a 25 year rotation. One factor that remains the same for all treatments was that a harvest rotation of 25 years resulted in the greatest economical return on investment. Inversely, the greatest loblolly pine and hardwood yields were the consequence of a 35-year rotation. This was expected due to the nature of compounding costs increasing as the rotation age increases. When examining each treatment by the greatest return on investment according to the gross value at harvest, treatment 4 was 81% higher than treatment 2, and 54% higher than treatment 3.

According to the estimated values from Table 9, for this study planting pines without any hardwood control (treatment 2) will result in the highest hardwood pulpwood yields and incur a net loss of economic returns following harvest. Minimal hardwood control (treatment 3) through hardwood stump treatment for planted pines resulted in a more balanced ratio of yields for loblolly pine and hardwoods. Economically, this treatment can be expected to break even following harvest. The greatest financial return was gained through the most intense hardwood control (treatment 4). Loblolly pine yield was highest and hardwood yield was lowest for this treatment as expected.

Table 9. Yield and economic summary for 13-year data per treatment carried to three different rotation ages for the Regeneration Alternatives Study.

	Treatment 2			Treatment 3			Treatment 4		
Stand Characteristics	**Age 25**	**Age 30**	**Age 35**	**Age 25**	**Age 30**	**Age 35**	**Age 25**	**Age 30**	**Age 35**
Mean dbh (in)	4.2	4.6	4.9	5.9	6.4	6.9	6.9	7.6	8.2
Basal area (ft^2/ac)	27.6	28.5	28.8	84.1	88.9	90.7	151.3	160.6	164
Yield (ft^3/acre) 8.0 in. 6.0 in. top									
Pulp	354.8	406.7	419.7	1354	1334.1	1202.1	1986.8	1715.4	1434
Sawlog	29.7	69.8	127.7	312.5	645.6	1014	1192.5	2102.9	2929.2
Hdwd yield (pulp)	1862.3	2154.3	2358.4	1262.6	1447.1	1579.4	548.6	607.9	656.5
Economic Characteristics (Pine and Hdwd Combined)									
Gross value at harvest ($)	212.76	268.19	322.04	523.26	746.33	969.00	1145.07	1685.66	2169.87
Net present value ($)	-14.56	-16.91	-20.02	5.89	5.69	-0.23	55.57	59.56	45.40
(Costs subtracted out)									
Internal rate of return (%)	5.02	4.99	4.82	7.39	7.32	6.99	9.16	8.88	8.28
R.O.I on hdwd control (%)	N/A	N/A	N/A	10.51	10.08	9.43	11.36	10.75	9.86

Input Parameters for Model

Stand Conditions	**Trt 2**	**Trt 3**	**Trt 4**
Number planted	1210	1210	1210
Site index	65	65	65
% hardwood BA	72.8	72.8	72.8
% hardwood reduction	19	49	73
hwd control	yes	yes	yes
Prices and Rates			
Pine pulp ($/cord)	15.50	15.50	15.50
Hdwd pulp ($/cord)	6.41	6.41	6.41
Sawtimber ($/MBF)	183.00	183.00	183.00
Discount rate (%)	7	7	7
Costs			
Site prep ($/acre)	0	0	0
Seedling ($/thousand)	0	0	0
Planting ($/acre)	39	39	39
Hdwd reduction ($/acre)	0	25	67
Harvest pine pulp ($/cord)	3	3	3
Harvest hdwd pulp ($/cord)	3	3	3
Harvest sawtimber ($/MBF)	60	60	60
Maintenance/Tax ($/acre/yr)	0	0	0

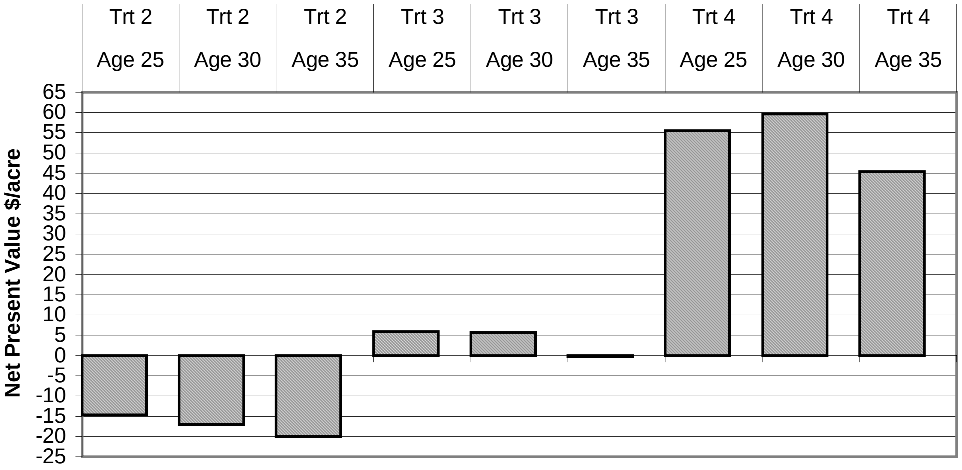


Figure 10. Economic returns following harvest by treatment and rotation age.

In order to approximate the effect of season of harvest for the model, the existing 13-year pine data was run through ECONHDWD for treatment 4. Three site index values were used to create a baseline index to estimate treatment 4 seasonal effects for the existing 13-year pine data (Table 10). When comparing mean dbh and basal area results from Table 10 with Tables 3A and 3B along with cross-referencing 13-year pine heights with a loblolly pine site index table (Appendix AB), an SI of 80 best approximated a summer harvest and an SI of 55 best approximated a winter harvest.

Further modeling was done to evaluate the economic and volume tradeoffs between harvests using the approximated effects of season of harvest through manipulating the site index parameter of the model (Table 11). Unlike Table 9, a seedling cost of $40 and a tax/maintenance cost of $2 were added as input parameters. These costs were added to better simulate the costs private landowners may be likely to incur.

Table 10. Thirteen-year stand data for treatment 4 modified by adjusting site index to approximate differing seasons of harvest for the Regeneration Alternatives Study.

Stand Characteristics	**Trt 4 Age 13**	**Trt 4 Age 13**	**Trt 4 Age 13**
Mean dbh (in)	4.4	4.8	5.3
Basal area (ft^2/ac)	86.4	100.4	123.1
Pine Yield (ft^3/acre) 8.0 in. 6.0. in. top			
Pulp	722.6	1114.3	1757.9
Sawlog	4.4	17.6	90.6
Hdwd yield (pulp)	185.3	272	415.2
Economic Characteristics			
(Pine and Hdwd Combined)			
Gross value at harvest ($)	140.44	222.56	390.37
Net present value ($)	**-72.99**	**-46.69**	**5.7**
(Costs subtracted out)			
Internal rate of return (%)	0	2.42	7.43
R.O.I on hdwd control (%)	1.64	5.97	11.31
Input Parameters for Model			
Stand Conditions	**Trt 4**	**Trt 4**	**Trt 4**
Number planted	1210	1210	1210
Site index	**55**	**65**	**80**
% hardwood BA	72.8	72.8	72.8
% hardwood reduction	73	73	73
hdwd control	Yes	Yes	Yes
Prices and Rates			
Pine pulp ($/cord)	15.5	15.5	15.5
Hdwd pulp ($/cord)	6.41	6.41	6.41
Sawtimber ($/MBF)	183	183	183
Discount rate (%)	7	7	7
Costs			
Site prep ($/acre)	0	0	0
Seedling ($/thousand)	0	0	0
Planting ($/acre)	39	39	39
Hdwd reduction ($/acre)	67	67	67
Harvest/haul pine pulp ($/cord)	3	3	3
Harvest/haul hdwd pulp ($/cord)	3	3	3
Harvest/haul sawtimber ($/MBF)	60	60	60
Maintenance/Tax ($/acre/yr)	2	2	2

Table 11. Yield and economic summary for the 13-year data for hardwood and mixed pine stands estimated at a 30-year rotation with varying degrees of site index for the Regeneration Alternatives Study.

Stand Characteristics	**Trt 1**	**Trt 2**	**Trt 3**	**Trt 4**		
Mean dbh (in)	2	4.8	7.5	6.8	7.6	9.1
Basal area (sq ft/ac)	2.5	31.5	119.3	129.1	160.6	224.4
Pine Yield (cu ft/acre) 8.0 in 6.0 in top						
Pulp	20.9	562	1588.1	1543.9	1715.4	1587.3
Sawlog	0	118.8	1841.3	940.2	2102.9	5563.3
Hdwd yield (pulp)	2459	3460.6	2190.2	451.2	607.9	669
Economic Characteristics (pine and hdwd combined)						
Gross value at harvest ($)	178.72	419.34	1608.8	900.21	1685.7	3884.3
Net present value ($)	**-12.2**	**-78.02**	**8.42**	**-91.25**	**-21.58**	**172.08**
(Costs subtracted out)						
Internal rate of return (%)	3.06	2.34	7.23	4.19	6.5	9.62
R.O.I on hdwd control (%)	N/A	N/A	N/A	7.56	9.97	13.25
Input Parameters for Model						
Stand Conditions	**Trt 1**	**Trt 2**	**Trt 3**	**Trt 4**		
Number planted	1210	1210	1210	1210	1210	1210
Site index	**65**	**80**	**80**	**55**	**65**	**80**
% hardwood BA	90	72.8	72.8	72.8	72.8	72.8
% hardwood reduction	0	19	49	73	73	73
hwd control	No	Yes	Yes	Yes	Yes	Yes
Prices and Rates						
Pine pulp ($/cord)	15.5	15.5	15.5	15.5	15.5	15.5
Hdwd pulp ($/cord)	6.41	6.41	6.41	6.41	6.41	6.41
Sawtimber ($/MBF)	183	183	183	183	183	183
Discount rate (%)	7	7	7	7	7	7
Costs						
Site prep ($/acre)	0	0	0	0	0	0
Seedling ($/thousand)	0	40	40	40	40	40
Planting ($/acre)	0	39	39	39	39	39
Hdwd reduction ($/acre)	0	0	25	67	67	67
Harvest/haul pine pulp ($/cord)	3	3	3	3	3	3
Harvest/haul hdwd pulp ($/cord)	3	3	3	3	3	3
Harvest/haul sawtimber ($/MBF)	60	60	60	60	60	60
Maintenance/Tax ($/acre/yr)	2	2	2	2	2	2

The hardwood control stands (treatment 1) proved to be less productive than the other treatments run through the model. However, due to minimal financial costs for natural regeneration, growing hardwood stands proved to have a higher net present value than treatment 2 on a site index of 80 and treatment 4 on site indices of 55 and 65. It must be noted that the program ECONHDWD was modeling outside standard operating parameters. The results for treatments 1, 2, and 3 from Table 11 are less robust than the results for treatment 4. This occurred because pine data used to approximate the effect of season of harvest came from the treatment 4 results for the 13-year age class. In addition, the summer season of harvest essentially decreased the amount of hardwood competition in the stands.

By manipulating the site index of the model, this effectively mirrors the beneficial growth towards pine after a summer harvest, but does not capture the negative effects towards the hardwood component. Hence, treatments 2 and 3 do not fully represent pine and hardwood growth results following a summer harvest. The modified site index values resulted in inflated hardwood pulpwood yields for treatments 2 and 3 as compared to treatment 1 yields. However, the results generated do provide insight to the future yields and economic values of stands carried to a 30-year rotation age. Pine stands planted after a summer harvest and prescribed a chemical control treatment like treatment 4 can realize a net present value of over $170 per acre. Treatment 4 following a summer harvest was clearly modeled as the most financially profitable of the three regeneration treatments.

CHAPTER 5
CONCLUSION

The four even-aged regeneration treatments applied to loblolly pine and mixed hardwood stands of this study had a significant effect on their growth. Loblolly pine growth increased and mixed hardwood growth decreased as the intensity of herbicide treatment increased for all age classes. In general, loblolly pine was more productive with more intense treatment applications on poorer sites following a growing season harvest. Hardwood species were more productive with less intense treatment applications on higher quality sites following a dormant season harvest for all age classes.

Growth parameters measured in the thirteenth year of the Regeneration Alternatives study confirmed many similar results reported for the fifth- and eighth-year studies. Loblolly pine planting following clearfelling, coupled with a herbicide stump and release treatment (treatment 4) resulted in the highest yields of loblolly pine, the greatest economical returns, and the greatest level of site utilization. However, treatment 4 also resulted in the lowest yield of mixed hardwoods and the lowest species richness and diversity. Loblolly pine planting following clearfelling, with (treatment 3) and without (treatment 2) a hardwood stump treatment application resulted in a more even distribution of pines and hardwoods depending on the treatment. Treatment 3 favored loblolly pine growth especially following a growing season harvest on poor sites. Treatment 2 favored mixed hardwood growth especially following a dormant season harvest on good sites.

The timing of the harvest has proven to have a very significant impact on the growth of pines planted on cut over hardwood sites. Pine yields, dbh, and basal area were all significantly greater following a summer season harvest as opposed to pine growth following a winter harvest with the same chemical treatments. The pine growth data indicated that less intense chemical treatments following a summer harvest can achieve the same or greater growth results than more intense chemical treatments following a winter harvest. This benefits private landowners by reducing the costs for hardwood control simply by adjusting the timing of the harvest, and reduces the amount of costs compounded into the future.

The results of this study indicate a significant biological and economical tradeoff depending on the level of hardwood control applied and the time of harvest. In terms of management for mixed pine-hardwood stands, it will ultimately depend on the landowners objectives. This study has provided insightful information that can lead to the development of varying levels of mixed pine-hardwood stands consequent to the level of herbicide application.

Economically, the best method of regeneration to garner the greatest return on investment would be to plant loblolly pine following clearfelling, chemically treat competing hardwood stumps and follow up with a release treatment. Of the four regeneration treatments examined for this study, treatment 4 was the only one that realized a substantial profit for the timber model simulation. Treatments 2 and 3 resulted in a net loss, except for treatment 3 following a summer harvest. If a landowner is interested in growing timber for revenue, treatment 4 applied after a growing season harvest will significantly increase site utilization of the pines and lead to merchantable timber at a younger rotation age.

Biologically, the best method of regeneration to enhance species richness, diversity, and stand composition was planting loblolly pine following a growing season harvest without any hardwood competition control.   This method of regeneration promoted the growth of mixed pine-hardwood stands, allowed for better site utilization over pure hardwood stands, and resulted in a more even distribution of species dominance within stand composition.

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APPENDICES

Appendix A. Split-Split Plot Anova on Fifth-Year Loblolly Pine Basal Area per Acre.

Source of Variation	DF	F Value	Pr>F
Block	2	0.97	0.4044
Site	1	2.26	0.1551
Block*Site	2	1.36	0.2875
Seas	1	122.04	0.0001
Site*Seas	1	1.73	0.2098
Block*Site*Seas	3	1.38	0.2909
Trt	2	10.34	0.0017
Seas*Trt	2	8.4	0.0040
Site*Trt	2	0.35	0.7126
Site*Seas*Trt	2	1.99	0.1735

Test of Hypothesis using Type III MS for Block*Site as error term

Source of Variation	DF	F Value	Pr>F
Block	2	0.71	0.5854
Site	1	1.65	0.3271

Test of Hypothesis using Type III MS for Block*Site*Seas as error term

Source of Variation	DF	F Value	Pr>F
Seas	1	88.69	0.0025
Site*Seas	1	1.26	0.3441

Appendix B. Split-Split Plot Anova on Fifth-Year Loblolly Pine Height (ft).

Source of Variation	DF	F Value	Pr>F
Block	2	0.94	0.4130
Site	1	1.83	0.1981
Block*Site	2	0.28	0.7593
Seas	1	10.98	0.0051
Site*Seas	1	0	0.9456
Block*Site*Seas	3	1.03	0.4075
Trt	2	7.45	0.0063
Seas*Trt	2	4.48	0.0313
Site*Trt	2	0.2	0.8232
Site*Seas*Trt	2	0.1	0.9033

Test of Hypothesis using Type III MS for Block*Site as error term

Source of Variation	DF	F Value	Pr>F
Block	2	3.36	0.2296
Site	1	6.5	0.1255

Test of Hypothesis using Type III MS for Block*Site*Seas as error term

Source of Variation	DF	F Value	Pr>F
Seas	1	10.62	0.0472
Site*Seas	1	0	0.9498

Appendix C. Split-Split Plot Anova on Fifth-Year Loblolly dbh (in).

Source of Variation	DF	F Value	Pr>F
Block	2	0.29	0.7508
Site	1	3.22	0.0945
Block*Site	2	1.19	0.3341
Seas	1	30.67	0.0001
Site*Seas	1	0.04	0.8404
Block*Site*Seas	3	0.77	0.5295
Trt	2	18.44	0.0001
Seas*Trt	2	4.3	0.0350
Site*Trt	2	0.15	0.8657
Site*Seas*Trt	2	0.06	0.9394

Test of Hypothesis using Type III MS for Block*Site as error term

Source of Variation	DF	F Value	Pr>F
Block	2	0.25	0.8023
Site	1	0.71	0.2415

Test of Hypothesis using Type III MS for Block*Site*Seas as error term

Source of Variation	DF	F Value	Pr>F
Seas	1	39.81	0.0080
Site*Seas	1	0.05	0.8303

Appendix D. Split-Split Plot Anova on Fifth-Year Hardwood Basal Area Per Acre.

Source of Variation	DF	F Value	Pr>F
Block	2	0.02	0.9849
Site	1	0.59	0.4510
Block*Site	2	1.06	0.3637
Seas	1	6.44	0.0191
Site*Seas	1	1.38	0.2531
Block*Site*Seas	3	1.41	0.2679
Trt	3	9	0.0005
Seas*Trt	3	1.09	0.3752
Site*Trt	3	0.19	0.8991
Site*Seas*Trt	3	0.19	0.8986

Test of Hypothesis using Type III MS for Block*Site as error term

Source of Variation	DF	F Value	Pr>F
Block	2	0.01	0.9859
Site	1	0.56	0.5337

Test of Hypothesis using Type III MS for Block*Site*Seas as error term

Source of Variation	DF	F Value	Pr>F
Seas	1	4.57	0.1221
Site*Seas	1	0.98	0.3952

Appendix E. Split-Split Plot Anova on Fifth-Year Hardwood dbh (in).

Source of Variation	DF	F Value	Pr>F
Block	2	0.38	0.6877
Site	1	0.16	0.6934
Block*Site	2	1.2	0.3217
Seas	1	2.9	0.1033
Site*Seas	1	4.02	0.0579
Block*Site*Seas	3	1.2	0.3345
Trt	3	2.57	0.0815
Seas*Trt	3	0.83	0.4905
Site*Trt	3	0.5	0.6832
Site*Seas*Trt	3	0.17	0.9136

Test of Hypothesis using Type III MS for Block*Site as error term

Source of Variation	DF	F Value	Pr>F
Block	2	0.32	0.7586
Site	1	0.13	0.7499

Test of Hypothesis using Type III MS for Block*Site*Seas as error term

Source of Variation	DF	F Value	Pr>F
Seas	1	2.42	0.2176
Site*Seas	1	3.36	0.1643

Appendix F. Split-Split Plot Anova on Fifth-Year Hardwood Richness.

Source of Variation	DF	F Value	Pr>F
Block	2	1.16	0.3326
Site	1	0.83	0.3715
Block*Site	2	0.37	0.6966
Seas	1	9.94	0.0048
Site*Seas	1	0.02	0.9019
Block*Site*Seas	3	1.27	0.3102
Trt	3	6.47	0.0028
Seas*Trt	3	0.20	0.8941
Site*Trt	3	0.25	0.8620
Site*Seas*Trt	3	2.28	0.1094

Test of Hypothesis using Type III MS for Block*Site as error term

Source of Variation	DF	F Value	Pr>F
Block	2	3.16	0.2406
Site	1	2.27	0.2711

Test of Hypothesis using Type III MS for Block*Site*Seas as error term

Source of Variation	DF	F Value	Pr>F
Seas	1	7.28	0.0680
Site*Seas	1	0.01	0.9189

Appendix G. Split-Split Plot Anova on Eighth-Year Loblolly Pine Basal Area per Acre.

Source of Variation	DF	F Value	Pr>F
Block	2	2.27	0.1402
Site	1	2.73	0.1205
Block*Site	2	1.4	0.2784
Seas	1	74.46	0.0001
Site*Seas	1	0.14	0.7167
Block*Site*Seas	3	0.27	0.8426
Trt	2	6.22	0.0117
Seas*Trt	2	5.98	0.0133
Site*Trt	2	0.04	0.9619
Site*Seas*Trt	2	0.81	0.4637

Test of Hypothesis using Type III MS for Block*Site as error term

Source of Variation	DF	F Value	Pr>F
Block	2	1.62	0.3822
Site	1	1.95	0.2975

Test of Hypothesis using Type III MS for Block*Site*Seas as error term

Source of Variation	DF	F Value	Pr>F
Seas	1	271.02	0.0005
Site*Seas	1	0.5	0.5308

Appendix H. Split-Split Plot Anova on Eighth-Year Loblolly Pine Height (ft).

Source of Variation	DF	F Value	Pr>F
Block	2	0.35	0.7085
Site	1	0.35	0.5647
Block*Site	2	0.7	0.5118
Seas	1	16.7	0.0011
Site*Seas	1	0.53	0.4802
Block*Site*Seas	3	0.56	0.6511
Trt	2	11.78	0.001
Seas*Trt	2	2.84	0.0921
Site*Trt	2	1.71	0.2164
Site*Seas*Trt	2	1.24	0.319

Test of Hypothesis using Type III MS for Block*Site as error term

Source of Variation	DF	F Value	Pr>F
Block	2	0.5	0.6655
Site	1	0.49	0.5546

Test of Hypothesis using Type III MS for Block*Site*Seas as error term

Source of Variation	DF	F Value	Pr>F
Seas	1	29.9	0.012
Site*Seas	1	0.94	0.4033

Appendix I. Split-Split Plot Anova on Eighth-Year Loblolly Pine dbh (in).

Source of Variation	DF	F Value	Pr>F
Block	2	0.09	0.9106
Site	1	1.51	0.2396
Block*Site	2	2.19	0.1492
Seas	1	30.91	0.0001
Site*Seas	1	0	0.9601
Block*Site*Seas	3	0.2	0.8934
Trt	2	21.4	0.0001
Seas*Trt	2	4.15	0.0384
Site*Trt	2	0.66	0.5323
Site*Seas*Trt	2	0.61	0.5553

Test of Hypothesis using Type III MS for Block*Site as error term

Source of Variation	DF	F Value	Pr>F
Block	2	0.04	0.9587
Site	1	0.69	0.4935

Test of Hypothesis using Type III MS for Block*Site*Seas as error term

Source of Variation	DF	F Value	Pr>F
Seas	1	153.19	0.0011
Site*Seas	1	0.01	0.9169

Appendix J. Split-Split Plot Anova on Eighth-Year Hardwood Basal Area Per Acre.

Source of Variation	DF	F Value	Pr>F
Block	2	0.93	0.4119
Site	1	3.74	0.0666
Block*Site	2	3.49	0.0490
Seas	1	12.99	0.0017
Site*Seas	1	5.39	0.0304
Block*Site*Seas	3	3.14	0.0471
Trt	3	23.7	0.0001
Seas*Trt	3	1.27	0.3104
Site*Trt	3	0.98	0.4224
Site*Seas*Trt	3	1.3	0.3011

Test of Hypothesis using Type III MS for Block*Site as error term

Source of Variation	DF	F Value	Pr>F
Block	2	0.26	0.7906
Site	1	1.07	0.4094

Test of Hypothesis using Type III MS for Block*Site*Seas as error term

Source of Variation	DF	F Value	Pr>F
Seas	1	4.14	0.1346
Site*Seas	1	1.72	0.2812

Appendix K. Split-Split Plot Anova on Eighth-Year Hardwood dbh (in).

Source of Variation	DF	F Value	Pr>F
Block	2	1.3	0.2945
Site	1	0.55	0.4675
Block*Site	2	0.2	0.8202
Seas	1	3.77	0.0656
Site*Seas	1	0.63	0.4374
Block*Site*Seas	3	3.83	0.0248
Trt	3	1.24	0.3195
Seas*Trt	3	1.26	0.3128
Site*Trt	3	2.21	0.1170
Site*Seas*Trt	3	0.7	0.5623

Test of Hypothesis using Type III MS for Block*Site as error term

Source of Variation	DF	F Value	Pr>F
Block	2	6.48	0.1337
Site	1	2.74	0.2399

Test of Hypothesis using Type III MS for Block*Site*Seas as error term

Source of Variation	DF	F Value	Pr>F
Seas	1	0.99	0.3940
Site*Seas	1	0.16	0.7129

Appendix L. Split-Split Plot Anova on Eighth-Year Hardwood Richness.

Source of Variation	DF	F Value	Pr>F
Block	2	0.99	0.3872
Site	1	10.12	0.0045
Block*Site	2	0.79	0.4672
Seas	1	5.97	0.0235
Site*Seas	1	1.9	0.1825
Block*Site*Seas	3	0.83	0.4906
Trt	3	1.26	0.3123
Seas*Trt	3	2.73	0.0699
Site*Trt	3	1.89	0.1618
Site*Seas*Trt	3	1.25	0.3172

Test of Hypothesis using Type III MS for Block*Site as error term

Source of Variation	DF	F Value	Pr>F
Block	2	1.26	0.4429
Site	1	12.82	0.0699

Test of Hypothesis using Type III MS for Block*Site*Seas as error term

Source of Variation	DF	F Value	Pr>F
Seas	1	7.16	0.0753
Site*Seas	1	2.28	0.2281

Appendix M. Split-Split Plot Anova on Thirteenth-Year Loblolly Pine Basal Area per Acre.

Source of Variation	DF	F Value	Pr>F
Block	2	2.25	0.1418
Site	1	5.68	0.0319
Block*Site	2	3.43	0.0613
Seas	1	60.7	0.0001
Site*Seas	1	0.5	0.4915
Block*Site*Seas	3	0.87	0.4783
Trt	2	20.11	0.0001
Seas*Trt	2	2.25	0.1424
Site*Trt	2	0.4	0.6748
Site*Seas*Trt	2	0.07	0.9333

Test of Hypothesis using Type III MS for Block*Site as error term

Source of Variation	DF	F Value	Pr>F
Block	2	0.66	0.6036
Site	1	1.65	0.3271

Test of Hypothesis using Type III MS for Block*Site*Seas as error term

Source of Variation	DF	F Value	Pr>F
Seas	1	69.52	0.0036
Site*Seas	1	0.57	0.5045

Appendix N. Split-Split Plot Anova on Thirteenth-Year Loblolly Pine Height (ft).

Source of Variation	DF	F Value	Pr>F
Block	2	1.31	0.3006
Site	1	0.09	0.7640
Block*Site	2	1.06	0.3743
Seas	1	6.84	0.0204
Site*Seas	1	1.96	0.1828
Block*Site*Seas	3	0.35	0.7916
Trt	2	0.64	0.5418
Seas*Trt	2	2.92	0.0874
Site*Trt	2	0.02	0.9801
Site*Seas*Trt	2	2.22	0.1449

Test of Hypothesis using Type III MS for Block*Site as error term

Source of Variation	DF	F Value	Pr>F
Block	2	1.24	0.4459
Site	1	0.09	0.7938

Test of Hypothesis using Type III MS for Block*Site*Seas as error term

Source of Variation	DF	F Value	Pr>F
Seas	1	19.67	0.0213
Site*Seas	1	5.65	0.0978

Appendix O. Split-Split Plot Anova on Thirteenth-Year Loblolly Pine dbh (in).

Source of Variation	DF	F Value	Pr>F
Block	2	0.08	0.9221
Site	1	2	0.1796
Block*Site	2	1.46	0.2651
Seas	1	18.8	0.0070
Site*Seas	1	0.91	0.3554
Block*Site*Seas	3	0.4	0.7564
Trt	2	14.16	0.0004
Seas*Trt	2	5.42	0.0180
Site*Trt	2	1.2	0.3291
Site*Seas*Trt	2	2.1	0.1595

Test of Hypothesis using Type III MS for Block*Site as error term

Source of Variation	DF	F Value	Pr>F
Block	2	0.06	0.9472
Site	1	1.37	0.3631

Test of Hypothesis using Type III MS for Block*Site*Seas as error term

Source of Variation	DF	F Value	Pr>F
Seas	1	47.21	0.0063
Site*Seas	1	2.29	0.2272

Appendix P. Split-Split Plot Anova on Thirteenth-Year Hardwood Basal Area Per Acre.

Source of Variation	DF	F Value	Pr>F
Block	2	1.41	0.2670
Site	1	14.32	0.0011
Block*Site	2	6.8	0.0053
Seas	1	24.93	0.0001
Site*Seas	1	5.99	0.0233
Block*Site*Seas	3	4.41	0.0148
Trt	3	40.25	0.0001
Seas*Trt	3	1.86	0.1680
Site*Trt	3	1.06	0.3871
Site*Seas*Trt	3	1.38	0.2771

Test of Hypothesis using Type III MS for Block*Site as error term

Source of Variation	DF	F Value	Pr>F
Block	2	0.21	0.8286
Site	1	2.11	0.2839

Test of Hypothesis using Type III MS for Block*Site*Seas as error term

Source of Variation	DF	F Value	Pr>F
Seas	1	5.65	0.0978
Site*Seas	1	1.36	0.3281

Appendix Q. Split-Split Plot Anova on Thirteenth-Year Hardwood dbh (in).

Source of Variation	DF	F Value	Pr>F
Block	2	10.05	0.0009
Site	1	0.07	0.7983
Block*Site	2	1.67	0.2131
Seas	1	5.23	0.0327
Site*Seas	1	7.64	0.0116
Block*Site*Seas	3	1.17	0.3463
Trt	3	6.73	0.0023
Seas*Trt	3	1.29	0.3051
Site*Trt	3	2.98	0.0546
Site*Seas*Trt	3	0.99	0.4178

Test of Hypothesis using Type III MS for Block*Site as error term

Source of Variation	DF	F Value	Pr>F
Block	2	6.03	0.1421
Site	1	0.04	0.8596

Test of Hypothesis using Type III MS for Block*Site*Seas as error term

Source of Variation	DF	F Value	Pr>F
Seas	1	4.49	0.1244
Site*Seas	1	6.55	0.0833

Appendix R. Split-Split Plot Anova on Thirteenth-Year Hardwood Richness.

Source of Variation	DF	F Value	Pr>F
Block	2	4.23	0.0285
Site	1	46.78	0.0001
Block*Site	2	0.26	0.7746
Seas	1	1.29	0.2682
Site*Seas	1	0.4	0.5361
Block*Site*Seas	3	2.03	0.1405
Trt	3	4.63	0.0123
Seas*Trt	3	2.19	0.1198
Site*Trt	3	0.48	0.6971
Site*Seas*Trt	3	0.9	0.4579

Test of Hypothesis using Type III MS for Block*Site as error term

Source of Variation	DF	F Value	Pr>F
Block	2	16.38	0.0575
Site	1	180.99	0.0055

Test of Hypothesis using Type III MS for Block*Site*Seas as error term

Source of Variation	DF	F Value	Pr>F
Seas	1	0.64	0.483
Site*Seas	1	0.19	0.6887

Appendix S. Split-Split Plot Anova on Thirteenth-Year Loblolly Pine Yield (ft^3/ac).

Source of Variation	DF	F Value	Pr>F
Block	2	1.21	0.3285
Site	1	0.98	0.3385
Block*Site	2	2.74	0.0988
Seas	1	40.97	0.0001
Site*Seas	1	0	0.9731
Block*Site*Seas	3	1.03	0.4074
Trt	2	9.63	0.0023
Seas*Trt	2	1.1	0.3614
Site*Trt	2	0.48	0.6293
Site*Seas*Trt	2	0.15	0.8653

Test of Hypothesis using Type III MS for Block*Site as error term

Source of Variation	DF	F Value	Pr>F
Block	2	0.44	0.6945
Site	1	0.36	0.6104

Test of Hypothesis using Type III MS for Block*Site*Seas as error term

Source of Variation	DF	F Value	Pr>F
Seas	1	39.59	0.0081
Site*Seas	1	0	0.9752

Appendix T. Split-Split Plot Anova on Thirteenth-Year Hardwood Yield (ft^3/ac).

Source of Variation	DF	F Value	Pr>F
Block	2	2.52	0.1044
Site	1	10.92	0.0034
Block*Site	2	5.44	0.0125
Seas	1	13.83	0.0013
Site*Seas	1	7.86	0.0107
Block*Site*Seas	3	3.73	0.0272
Trt	3	20.25	0.0001
Seas*Trt	3	2.15	0.1249
Site*Trt	3	3.01	0.0533
Site*Seas*Trt	3	1.24	0.3189

Test of Hypothesis using Type III MS for Block*Site as error term

Source of Variation	DF	F Value	Pr>F
Block	2	0.46	0.6833
Site	1	2.01	0.2921

Test of Hypothesis using Type III MS for Block*Site*Seas as error term

Source of Variation	DF	F Value	Pr>F
Seas	1	3.71	0.1497
Site*Seas	1	2.11	0.2424

Appendix U. Anova for LSD test on Fifth-Year Loblolly Pine dbh (in).

Source of Variation	DF	F Value	Pr>F
Block	2	0.73	0.5134
Site	1	6.46	0.0389
NewTrmt	5	31.8	0.0001
Block*Site	2	1.91	0.2175
Block*NewTrmt	10	2.77	0.0945
Site*NewTrmt	5	0.2	0.9522

Appendix V. Anova for LSD test on Fifth-Year Loblolly Pine Basal Area per Acre.

Source of Variation	DF	F Value	Pr>F
Block	2	0.4	0.6826
Site	1	0.7	0.4310
NewTrmt	5	33.26	0.0001
Block*Site	2	0.21	0.8181
Block*NewTrmt	10	1.3	0.3730
Site*NewTrmt	5	0.74	0.6179

Appendix W. Anova for LSD test on Fifth-Year Loblolly Pine Height (ft).

Source of Variation	DF	F Value	Pr>F
Block	2	2.02	0.2035
Site	1	4.18	0.0800
NewTrmt	5	13.24	0.0019
Block*Site	2	0.83	0.4732
Block*NewTrmt	10	2.38	0.1308
Site*NewTrmt	5	0.28	0.9095

Appendix X. Anova for LSD Test on Eighth-Year Loblolly Pine dbh (in).

Source of Variation	DF	F Value	Pr>F
Block	2	0.16	0.8575
Site	1	3.1	0.1216
NewTrmt	5	25.43	0.0002
Block*Site	2	3.58	0.0848
Block*NewTrmt	10	1.5	0.3044
Site*NewTrmt	5	0.93	0.5162

Appendix Y. Anova for LSD Test on Eighth-Year Loblolly Pine Height (ft).

Source of Variation	DF	F Value	Pr>F
Block	2	1.16	0.3675
Site	1	1.09	0.3318
NewTrmt	5	25.5	0.0002
Block*Site	2	0.2	0.8201
Block*NewTrmt	10	0.46	0.8696
Site*NewTrmt	5	0.3	0.8959

Appendix Z. Anova for LSD Test on Thirteenth-Year Loblolly Pine dbh (in).

Source of Variation	DF	F Value	Pr>F
Block	2	0.12	0.8885
Site	1	4.36	0.0633
NewTrmt	5	23.97	0.0001
Block*Site	2	2.79	0.1089
Block*NewTrmt	10	1.8	0.1837
Site*NewTrmt	5	3.07	0.0619

Appendix AA. Testing of Significant Difference between Means for Chemical Release Treatments of Treatment 4.

TTEST PROCEDURE : Treatment 4.1 was the triclopyr basal spray and 4.2 was the hexazinone spot treatment.

```
Variable: DIAMETER

RELEASE      N         Mean              Std Dev      Std Error       Minimum       Maximum
----------------------------------------------------------------------------------------------------------------------
     1           379     5.65963061     1.39452098     0.07163173     2.00000000     11.00000000
     2           374     5.60962567     1.47454300     0.07624680     2.00000000      9.00000000

Variances       T          DF    Prob>|T|
-----------------------------------------------
Unequal     0.4780    747.4      0.6328
Equal         0.4782    751.0      0.6327

For H0: Variances are equal, F’ = 1.12    DF = (373,378)    Prob>F’ = 0.2799
```

****

```
Variable: HT

RELEASE      N         Mean              Std Dev      Std Error       Minimum       Maximum
-----------------------------------------------------------------------------------------------------------------------
     1          379    40.97282322     5.77844244     0.29681865     16.40000000     58.10000000
     2          374    40.06363636     7.43146442     0.38427188     12.80000000     55.80000000

Variances       T              DF    Prob>|T|
---------------------------------------------------
Unequal        1.8725    703.7      0.0616
Equal            1.8755    751.0      0.0611

For H0: Variances are equal, F’ = 1.65    DF = (373,378)    Prob>F’ = 0.0000
```

Appendix AB. Loblolly Pine Site Index Table.

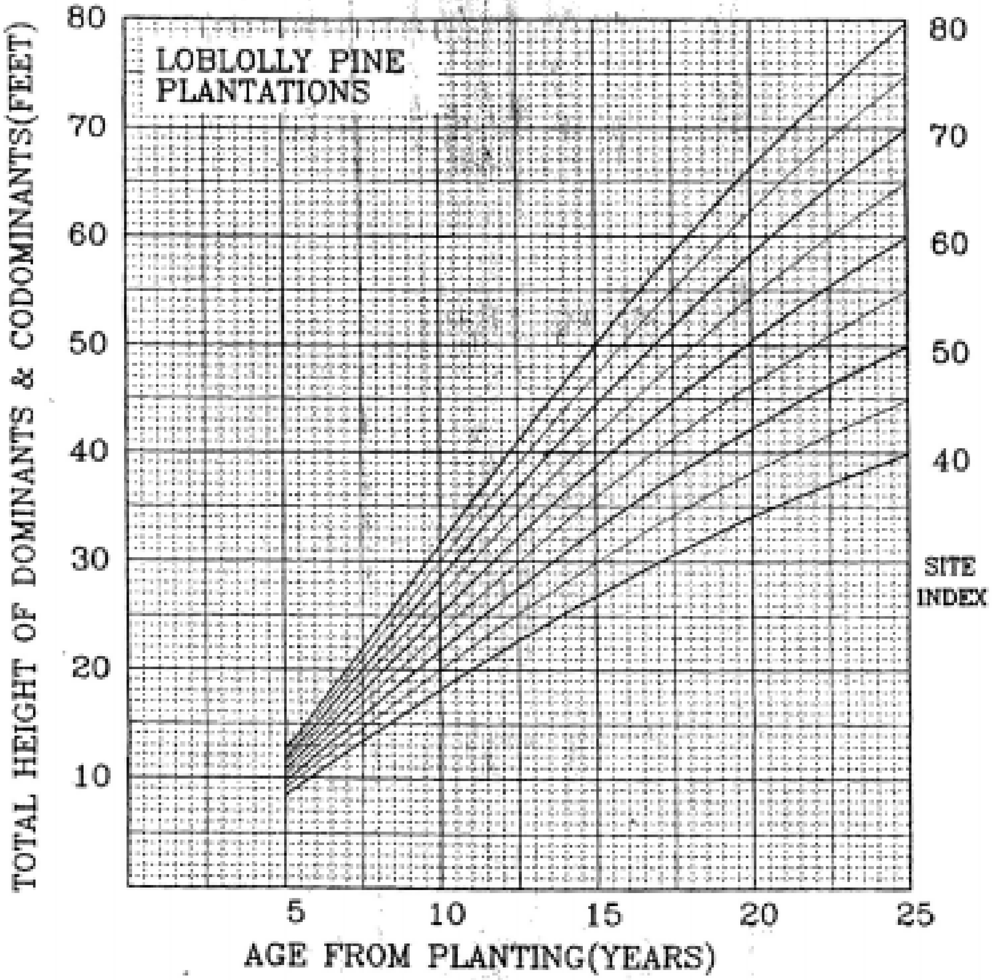

Figure 115.—Loblolly pine plantations--Piedmont (Amateis and Burkhart 1985)
Piedmont throughout most of natural range
68 plots, cutover and site prepared land, 1 dominant and 1
codominant tree on each plot
Stem analysis, differential equation, polymorphic
Site index is total height at 25 years since planting
Convert d.b.h. age to age since planting by adding years according
to site index (BH = 0.0):
SI: <50 >50
Years: 3 2

	b_1	b_2	b_3	b_4	b_5	R^2	SE	Maximum difference
H	1.0069	1.1098	-0.0535	0.5548	0.2433	0.99	0.01	0.4
SI	0.8459	1.0028	-0.1241	-1.4087	0.2398	0.99	0.01	3.4

VITA

Jason Alexander Heinze was born in Baltimore, Maryland, in 1968. He grew up in the northeast and graduated high school in Canton, Massachusetts. After graduation, Jason enrolled in the armed forces with the U.S Army. He served four years of active duty with the 101st Screaming Eagles at Fort Campbell, Kentucky. During his term of service, he successfully completed Airborne, Air Assault, and Ranger training as well as a tour of duty in the Persian Gulf. In 1991, he completed his military service honorably and went on to receive a Bachelor of Science degree in Forestry and Wildlife Biology from the State University of New York College of Environmental Science and Forestry in Syracuse. Shortly after graduation, he began his studies at Virginia Polytechnic Institute and State University, where he graduated with a Master of Science in Forestry with an emphasis in silviculture. Jason currently resides in Chillicothe, Ohio, with his wife and son and works as a Land Management Forester with Mead Paper Corporation.