EFFECTS OF ALTERNATIVE SILVICULTURAL TREATMENTS ON REGENERATION IN THE SOUTHERN APPALACHIANS

by

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Abstract

Harvesting practices in the southern Appalachians have moved away from clearcutting in favor of variable retention harvesting systems. A study was initiated in 1995-8 to investigate the effects of retaining varying numbers of residual trees on regeneration in seven silvicultural treatments. A second study specifically focused on stump sprouting in only three of those treatments. The treatments for first study included: a clearcut, commercial harvest, leave-tree, shelterwood, group selection, midstory treatment, and an uncut control. The second only focused on the clearcut, leave-tree, and shelterwood.

These treatments were implemented in seven stands in Virginia and West Virginia over two physiographic provinces, the Appalachian plateau and Ridge and Valley. The stands were even-aged oak dominated Appalachian hardwood stands on fair quality sites with average ages ranging from 63 to 100 yrs. Permanent plots were randomly located in each stand and all overstory trees (>5m tall) were inventoried and tagged prior to harvest. Regeneration was also quantified. Harvest occurred between 1995-8. For the current studies the plots were re-inventoried 9-11 years post-harvest and all regeneration in all treatments as well as stump sprouts in the selected treatments were quantified.

The first study utilized a mixed model ANOVA to analyze five species groups: oak, maple, black cherry-yellow-poplar, miscellaneous, and midstory. Response variables included importance value, average height, and density compared within species group and among treatments. Differences between sprout and seedling origin regeneration were also investigated within species group among treatment. Results indicated that oak densities were similar in all of the treatments, and stump sprouts were larger and more frequent than seedlings. Maple exhibited an increase from pre-harvest overstory importance and exhibited competitive sprouting. The black cherry-yellow-poplar group had few but highly competitive sprouts and a considerable increase in seedling origin regeneration in all treatments. The miscellaneous species densities increased as well with more competitive sprouting in some treatments. The midstory species were excluded from the analysis as it was assumed these species would not occupy canopy positions in a mature stand.

The second study investigated differences in the percent of stumps that sprouted and the number of sprouts per stump. The percent data were analyzed using a non-parametric one-way ANOVA and regression analysis, while the sprouts per stump data were compared in a mixed model ANOVA and regression. Species were combined into six groups: the red oak group, chestnut oak, red maple, white oak/hickory group, mixed mesic group, and midstory group. The plateau tended to have reduced sprouting compared to the Ridge and Valley for most species groups and treatments. The red oak group, chestnut oak, and red maple exhibited reduced sprouting with increased residual basal area. The mixed mesic group did not show any effect in sprouting related to residual basal area. Only chestnut oak showed fewer sprouts per stump as residual basal area increased.

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1. Introduction

Justification

The United States South contains 24% of the country's land base but 40% of the nation's timberlands. These forest areas are considered to be among the most productive in the United States (Wear 1995). In 2003 the Mountain Region of the South produced 483 million cubic feet of roundwood (Johnson et al. 2006). This was only 6% of the South's total timber production but nearly 25% of the South's total hardwood production. This production rate has leveled out since its recent peak in 1995. The southern Appalachians are known world wide for their quality hardwood timber production and products (Appalachian Hardwood Manufactures 2007). Currently international 1/4" stumpage prices in southwest Pennsylvania are northern red oak (*Quercus rubra* L.) \$354/MBF, white oak (*Q. alba* L.) \$305/MBF, and soft maple (*Acer rubrum* L.) \$252/MBF (Pennsylvania Timber Market Report 2008).

The productive high value hardwood forests in the southern/central Appalachian hardwood region stretch from the tip of the southern tier of New York through most of Pennsylvania to northern Georgia and north central Alabama. This area is the largest contiguous temperate hardwood forest in the world (Smith 1994). Within this area the forest occupies an array of landforms, climates, soils, and geology. This in combination with a dynamic past helps to support a very diverse and unique ecosystem (Stephenson 1993). This has presented numerous distinct forest management challenges related to species interactions and diversity.

The impetus for this study has been a shift in land use, changes in forest management activities, and lack of understanding of the effects of these alternative management techniques on regeneration. In the 1960's clearcutting was promoted as the most effective and efficient form of timber management in this region (Roach and Gingrich 1968). The term alternative silvicultural practices, or variable retention harvest systems, refers to new regeneration and forest management techniques that offer alternatives to traditional even-aged management (Franklin 1997). The alternative silvicultural practices have more diverse goals than those of previous systems. The retention of structural elements can serve multiple objectives. These elements can fulfill the habitat needs of species requiring more structurally diverse canopy strata or gaps, soften the aesthetic impacts of timber harvesting, provide a lifeboat for refugia and inocula in the next stand, and help retain some areas of undisturbed microclimate conditions (Franklin 1997). However little is known as to the effects of these alternative silvicultural systems on the biodiversity and sustainability of the southern Appalachian hardwood forest ecosystems.

This study titled "What mechanisms control understory biodiversity, resilience, and nutrient processes in managed Appalachian forest ecosystems?" (Referred to as the Diversity Study) was designed to investigate the effects of some of the common alternative silvicultural practices implemented in this area on salamander, floral, and tree species diversity. This thesis focuses on the effects of the alternative silvicultural techniques on the sustainability of commercially important timber and non-timber tree species.

To quantify any differences, seven replicate sites were distributed on two of the three major physiographic provinces of the southern Appalachians, the Ridge and Valley and the Appalachian plateau. The Blue Ridge was not included. These sites are located on both Forest Service lands in the Jefferson National Forest of southwest Virginia and on private timber industry lands in central West Virginia, formerly owned by the MeadWestvaco Corporation as the Wildlife and Ecosystem Research Forest, but currently owned and managed by Penn Virginia Resource Partners. Each site served as a block with one replicate of seven treatments at each site. One site was an exception with only five of the treatments. These sites have yielded papers, theses, and dissertations regarding pre and post harvest soil erosion, light levels, soil nitrogen levels, salamander populations, and herbaceous diversity differences among the treatments and over time (Hammond 1997, Harpole and Haas 1999, Wender 1999, Hood 2001, Lorber 2002, Knapp et al. 2003, Belote et al. 2008). Current research is focused on the long-term effects of these treatments on tree regeneration, specifically focusing on commercially and ecologically important species, such as oaks (*Quercus* spp.).

Oaks are a keystone species in the forests of the southern Appalachians. The entire southern Appalachian Oak Forest Region encompasses over 80,000 km^2 (Stephenson et al. 1993). This forest type is home to some 228 terrestrial vertebrate species, mostly in birds and mammals; however, it also contains potentially the most diverse salamander fauna in North America (Stephenson et al. 1993). Acorn production by oaks is an important food source for wildlife. It is considered a hard mast crop that can often be stored for later consumption, or used to build fat reserves for winter survival. There are currently no replacements for this type of food source within this forest type (McShea et al. 2007).

This study is unique with regard to its in-depth nature, volume and diversity of data, and long term goals. Most studies of this nature only track a certain aspect of an ecological system, whereas this study is focused on multiple ecological aspects at the same sites over a long period of time. Currently research studies on the impacts of these alternative silvicultural treatments on salamander, herbaceous, and tree species diversity and population dynamics are being investigated. Also related studies, on stump nutrient and organic matter importance in carbon and nitrogen pools, the uses of ground penetrating radar to map soils, coarse fragment and bedrock heterogeneity, importance of leaf litter to invasion resistance, and the impacts of salamander populations on nutrient cycling for this general region, are being conducted.

Objectives and hypotheses

In this research I looked at alternative silvicultural practices for harvesting and regenerating oak dominated stands in the southern Appalachians by quantifying the regeneration 9-11 years after harvest. This involved a full inventory of all of the diversity study research plots in the Ridge and Valley and Appalachian plateau physiographic provinces of the southern Appalachian Mountains. I compared species among treatments to find if there were any treatment affects. Pre-harvest data were used to see if any species shifts from the composition of the original overstory can be identified. A more complete survey of the stumps within the clearcut, leave-tree, and shelterwood treatments was conducted to see if any differences in stump sprouting can be attributed to the number of residual trees left in the stand. Specific objectives were:

i) quantify all regeneration 9 to 11 years post-harvest at all sites and in all treatments

ii) quantify any regeneration differences among treatments in terms of species height, density, and origin

iii) quantify any differences in number of residual tree defects among the treatments

iv) quantify any differences in the number and vigor of stump sprouts, of all species, especially oaks, among the clearcut, leave-tree, and shelterwood treatments

Specific hypotheses to be tested are:

1) Residual trees will shade the regeneration impeding growth rates.

   $H_{0,1}$: There is no difference in regeneration height among treatment.

2) Shade intolerant species will be more prevalent in those treatments which maximize light levels to the regeneration.

   $H_{0,2}$: There is no difference in the density of competitive stems by species among treatment.

3) Stump sprouts will be more competitive than seedling or advance origin regeneration.

   $H_{0,3}$: There is no difference between competitiveness and regeneration origin.

4) The number of bole defects is increased on residuals in those treatments which maximized light exposure of the bole.

   $H_{0,4}$: There is no difference in the number of bole defects among treatment.

5) More stumps sprout in the treatments with fewer residuals trees.

   $H_{0,5}$: There is no difference among treatments in the proportion of stumps which sprout.

6) Stump sprouts are more vigorous in the treatments with fewer residual trees.

   $H_{0,6}$: There is no difference among treatments in the vigor of stumps that sprout.

2. Literature Review

Background of the Southern Appalachians

This area of the Appalachians has been classified as the Oak-Chestnut forest region (Braun 1950). It was so classified because of the dominance of oak and formerly American chestnut (*Castanea dentata* Marsh. Borkh.) with some dominance of yellow-poplar (*Liriodendron tulipifera* L.) on more mesic cove and bench sites. The oak dominated hardwood forests found in the southern Appalachian mountains today are the result of a number of both long and short term natural and anthropogenic disturbance events that drastically altered and shaped the geology, landscape/topography, climate, and species composition of the area.

The Appalachians have their roots in the Appalachian Orogeny, which began 470 million years ago and ended 240 million years ago (Roll 1992). In this orogeny, layers of sedimentary rock from a shallow inland sea were uplifted, folded, and faulted as a result of the collision of the North American and European plates. The Plateau physiographic provinces consist of horizontally oriented strata that sit to the west of the Appalachians. These layers were heaved up and now tilt to the north and west. Another section of these sedimentary rock layers were folded, faulted, and uplifted into a parallel belt of mountains known today as the Ridge and Valley physiographic province, which is the heart of the Oak-Chestnut forest region (Braun 1950).

The two physiographic provinces of focus in this research are the central Ridge and Valley province and the Appalachian plateau to its west. The Ridge and Valley is defined by strongly dissected parallel ridges and valleys, which formed from differential erosion, mass wasting, fluvial transport, and deposition (McNab 1996). This section consists of sandstone ridges with layers of shale, and limestone valleys. These bedrocks were folded, faulted, and uplifted to form a vertically structured stratum. The limestone and shale weathered more quickly than the more resistant sandstone leaving it to stand higher as ridges with shallow, more acidic, rocky, less fertile, and more steeply sloped soils. The deep fertile soils of the wider and more level valleys were highly conducive to settlement by the first residents of this area some 12,000 years ago (Yarnell 1998). The

Appalachian plateau to the west also formed from the differential weathering of sedimentary rock; however, this stratum is oriented horizontally. The plateau tops are mostly deeper sandstone derived acidic soils that have formed from weather-resistant sandstones such as a Muskingum series, a fine-loamy, mixed, semiactive, mesic Typic Dystrudept (NRCS 2006). The valleys are deep cuts formed by streams and landslides. Once these streams weathered through the resistant sandstone and reached the much more easily weathered lays of shale, siltstone, and limestone they cut much more deeply into the landscape. The first European settlers to this area only farmed the fertile valleys and stayed close to the rivers for transportation (Whiney 1990). Only later did they begin to clear, settle, and farm the deeper soils on the plateau tops.

The climate of this area only stabilized about 4,000 years ago. About 18,000 yr. B.P. the southern movement of the Wisconsin glaciers peaked. This forced boreal forests and mixed conifer – northern hardwoods down into the southern Appalachians (Delcourt and Delcourt 1993). The tree species diversity currently found in eastern North America is attributed in part to the fact the Appalachians run north south, which allowed for the migration of many plant genera during glacial periods. After this time the glaciers slowly retreated north and the climate throughout the Appalachians became hospitable to temperate species once again. It is thought that for the past 4,000 years oaks, pines (*Pinus* spp.), and American chestnut dominated most Appalachian stands (Brose et al. 2001). The climate of Ridge and Valley today is somewhat variable, with average annual temperatures ranging between 13 and 16 ^{o}C, the growing season averages between 170 and 210 days, and with the western most ridges receiving some 140 cm of annual precipitation, while some of the more eastern areas, suffer a rain shadow effect caused by the higher ridges, only receive 92 cm annually (McNab 1996). The Appalachian plateau province has an excellent tree growing climate with an average of 122-132 cm of rain annually and on average 150 frost free days a year (Smith 1994).

In the Ridge and Valley the ridges would have had scarlet (*Q. coccinea* Muenchh.), and chestnut oak (*Q. prinus* L.), American chestnut, and Virginia (*Pinus virginiana* Mill.), pitch (*P. rigida* Mill.), and table-mountain (*P. pungens* Lamb.) pine growing on the ridge top sandstone residuum soils. These soils are younger and less well developed such as Berks series, described as a Loamy-skeletal, mixed, active, mesic

Typic Dystrudept (NRCS 2006). Black (*Q. velutina* Lam.), northern red, and white oak, yellow-poplar, American basswood (*Tillia americana* L.), and eastern white pine (*Pinus strobus* L.) occupied the richer side slope colluvium sites such as Jefferson soil series, a Fine-loamy, siliceous, semiactive, mesic Typic Hapludult (NRCS 2006). Steep shale residuum side slopes hosted white oak and Virginia and pitch pine on shallow Weikert soil series, a Loamy-skeletal, mixed, active, mesic Lithic Dystrudept (NRCS, 2006). The alluvium bottoms being of high site quality would host the most species diversity being dominated by white and red oak and yellow-poplar on soils such as the Craigsville soil series, a Loamy-skeletal, mixed, superactive, mesic Fluventic Dystrudept (NRCS 2006).

Many of the Appalachian Plateau top forests were originally eastern hemlock (*Tsuga canadensis* (L.) Carrière), American beech (*Fagus grandifolia* Ehrh.), and eastern white pine of most impressive size. As technology improved such as narrow gage railroad and the Shay's locomotive engine, more areas could be timbered (Yarnell 1998). Vast clearcutting led to the build up of an enormous amount of slash, which led to catastrophic fires. New sources of ignition such as logging trains continually ignited the large fires. In the wake of these fires a new cohort of shade intolerant species came to replace the tolerant beech and hemlock. Yellow-poplar, black cherry (*Prunus serotina* Ehrh.), white ash (*Fraxinus Americana* L.), red oak, basswood, and red (*Acer rubrum* L.) and sugar maple (*Acer saccharum* Marsh.) replaced the former forest types on better sites. On the more marginal sites this allowed for other fast growing fire tolerant species such as black oak, scarlet oak, and chestnut oak to be recruited into the overstory. Based on dendrochronologic analysis it is estimated this happened between 1900-1930 (Abrams 2003). More recently this area has been exploited for its vast bituminous coal reserves that sit parallel to the other layers of rock. Strip mining is a common form of extraction, and an extreme form of this, mountain top removal, is becoming more common.

The Native Americans often girdled trees and used fire to keep land cleared and facilitate better hunting grounds. Wood (1634) "There is no underwood saving in swamps and low grounds that are wet…for it being the custom of the Indians to burn the woods in November…" It is also thought early Europeans continued this tradition as suggested by Hammond (1880), "The early settlers in this region were stock raisers and kept up the Indian practice of burning off the woods during the winter." White oak seemed to thrive in the frequent, low intensity fires that shaped the eastern North American landscape during the Holocene epoch (Abrams 2003). This can be noted by its prevalence in many witness tree records (Abrams and Downs 1990, Rentch and Hicks 2005). Fires and even-age helophytic regeneration shaped these forests through the Era of Exploitation as many thousands of acres were cleared for lumber and fuel wood to make charcoal, which fueled the iron industry (Yarnell 1998).

In recent times fire suppression has drastically reduced the numbers of fires in the region. Education such as the Smokey Bear campaign and differing land uses along with people leaving the Appalachians has reduced the occurrence of fires. For example fires on the Jefferson National Forest decreased consecutively during the 1940's (Yarnell 1998). Also timber harvests from national forest have decreased after the clearcutting conflicts of the 1960's and 70's resulted in the Monongahela Decision of 1974, which prompted the 1976 National Forest Management Act (Yarnell 1998). This in conjunction with the National Environmental Policy Act (NEPA) process has drastically reduced timber production from the national forests of the Appalachians. However, harvesting on private lands remains high, much higher than that found on public lands (Wear and Flamm 1993).

Oak regeneration

This review will focus on the literature pertaining to the regeneration methods used in oak dominated forests of the eastern U.S. Specifically it will focus on the more recent works in the central and southern Appalachians. The most common oak species found in the southern Appalachians are red, white, black, scarlet, and chestnut oak. Oak regeneration has been a topic of research for foresters, ecologists, biologists, and wildlife biologists alike. Oak has come to represent a keystone species in the Appalachians for timber production, aesthetics, and wildlife value. It replaced the American chestnut as a mast producer and now many species, upwards of 228 vertebrates, can be found dwelling in these Appalachian oak stands (Stephenson et al. 1993).

Oak regeneration concerns were first identified in the literature in the 1930's and 1940's. Quantification of these problems began in the 1950's and 1960's (Clark 1993). Much of the early work was done in the midwest and northeast focusing on species composition shifts after harvest, or under mature stands in the absence of historic disturbance events, such as fire. The results of these works focused mostly on the form of the regeneration under these stands, and the sites on which regeneration differences occurred (Leffleman and Hawley 1925, Korstian 1927, Liming and Johnson 1944, Hawley 1946, Kuenzel and McGuire 1942, Bey 1964). This work set up an excellent foundation for modern oak investigations based on these core ideas, but it also led to some branching out as new findings have been concluded.

Currently natural oak regeneration work is focusing on four major areas. These are regeneration based on site quality, light levels and management, sources of regeneration, and favoring oak through different disturbance events or regimes. Site quality has proven itself to be an overriding factor in numerous studies (Beck and Hooper 1986, Blount et al. 1986, Crow 1988, Loftis 1990b, Cook et al. 1996, Larsen and Johnson 1998). It is more difficult to regenerate oak on better sites where it must compete with species more adapted to higher site quality growing conditions. Site quality has also been shown to have a large influence on a number of the other factors. Light management has evolved because of a number of factors and varies according to site quality (Cook et al. 1996). There are multiple forms of oak regeneration, which have been differentiated into classes; these forms are influenced by site, age, light levels, and origin (Sander 1972). The disturbance ecology of oak has also proven to be a strong influence over the current oak dominated stands and lack or exclusion of such disturbances has led to many stand composition shifts and some complete species conversions (Loftis 1985, Brose et al. 2001, Zaczek 2002, Abrams 2005, Nowacki and Abrams 2008).

Site Quality

Site quality has proven to be an overriding factor in predicting successful oak regeneration or possible post harvest species shifts after clearcutting (Beck and Hooper 1986). It can be used to determine under which conditions oak can compete successfully, or potentially be replaced with other species in specific stands. Forest site quality in the southern Appalachians is largely a function of moisture availability during the growing season. It is largely determined by factors such as soil texture, soil depth, drainage, aspect, slope, and topographic position (McNab 1988). This can be used to determine which alternative silvicultural systems should be used and if intermediate treatments may need to be implemented to favor oak. Oak has been described as xerophytic; meaning it is more competitive on higher moisture stress sites (Larsen and Johnson 1998). These drier-site-adapted oaks are normally out-competed and over-topped on better sites by faster growing more mesic species such as yellow-poplar (Beck and Hooper 1986). This susceptibility to being overtopped based on site index is noted in models designed to predict oak's post-harvest performance in the southern Appalachians (Loftis 1990b). As described in the introduction, plateau sites have higher rainfall, deeper soils, and therefore higher moisture availabilities and tend to be the better sites compared to ridge sites in the Ridge and Valley. Therefore, alternative silvicultural treatments, influencing other factors such as light levels, must be implemented to favor oak dominated stands on more mesic, higher quality sites in the southern Appalachians.

Light Management

All of the Appalachian oaks are termed as intermediates for shade tolerance with the exception of scarlet oak being intolerant (Burns and Honkala 1990). These oaks can't accumulate and persist in the understory as advance regeneration under closed canopy conditions (Loftis 1990a). Without light alterations to high-site quality closed canopy Appalachian forests oak seedlings from a single cohort typically die out (Larsen and Johnson 1998). Light management, if properly implemented, can be used to favor the intermediate shade tolerance of Appalachian oaks on higher quality sites. It has been recommended to increase light levels by removing 20% to 40% of the basal area depending on site quality, with less light, or basal area removal, for better sites. The time frame should be no less than 10 ten years before harvest (Loftis 1990a, Cook et al. 1996). This will allow for the establishment of competitive oak regeneration but does not promote the germination of less shade tolerant species such as yellow-poplar, which could overtop and out compete the oak regeneration (Beck and Hooper 1986). Studies have shown that red oak planted under 30% of full light were taller, had larger root-to-shoot ratios, and higher leaf areas than those grown under full or 10% of full sun light (Phares 1971). It has also been found that without any light management, treatments resulting in full light conditions on fair to good sites can lose 50-90% of the oak component of the original stands within one rotation (Cook et al. 1996).

Sources of Regeneration

Oak regeneration is broken down into one of three general forms; seedling, advance, or stump sprout origin. Seedlings are often not an important form of regeneration due to high mortality under canopy conditions and slower relative growth rates. Oaks, especially in the red oak group *Erythrobalanus*, in the Southern Appalachians are not dependable seed producers. It takes two years for acorns of this group to mature, which often leads to cyclic years of heavy mast production, followed by several years of very poor mast production (Loftis 1990a). This results in inconsistent flushes of seedlings. Also these seedlings tend to concentrate growth belowground, yielding a high root to shoot ratio (Larsen and Johnson 1998). This leads to oak seedlings being overtopped by competition under full light conditions on fair to high quality sites.

Advance oak regeneration has been categorized into a number of classes based on height and the number of times the root stock sprouts, or its age at the root collar (Sander 1972, Sander et al. 1976). Loftis (1991) related these strategies to Egler's (1954) concepts of relay floristics and initial floristics. He concluded the "applicability of the initial floristics composition pattern to hardwood stand development following disturbance" meaning that oak advance regeneration is a persistent strategy of reproduction, which must be present before the overstory is removed in order for oak to be successful in subsequent stands. With this persistent life strategy in mind, height growth, basal diameter, and apical dominance of red oak advance reproduction in stands prior to clearcutting and the probability of these stems for becoming codominants or dominants in the subsequent stand has been modeled (Loftis 1990b). This work was strongly based on and consistent with other classifications of advance regeneration by height (Sanders 1971, Sander 1972, Sander et al. 1976).

Stump sprouts are a much more common form of oak regeneration in the southern Appalachians. Studies have shown that 75% of harvested oak stems sprout, which is a much higher percentage, possibly significant, compared to the relevance of stump sprouting in the mid-west (Cook et al. 1996, Johnson 1977). It has been noted in several accounts that white oak, red oak, scarlet oak, and to some extent black oak's ability to stump sprout decreases with increasing age, diameter, stump height, and season of harvest (Cook et al. 1996, Weigle and Johnson 1998). Chestnut oak's ability to stump sprout does not seem to be influenced as much by these factors. The other oaks seem to sprout less and show reduced vigor as they age, increase in diameter, have taller stump heights, or are harvested during the growing season (Cook et al. 1996).

Stump sprouts are considered those sprouts which are produced from dormant buds near the base of a top killed tree or cut stump (Johnson et al. 2002). Dormant buds are buds that developed in leaf axils and therefore are still connected to the trees pith (Kozlowski and Pallardy 1997). This is opposed to adventitious buds, which form on old parts of the plant and are not formed at the stem tips or leaf axils. Adventitious buds are neither connected to the apical meristems nor the pith, resulting in minimized plant control of these structures through hormonal feedbacks (Kozlowski and Parrlardy 1997, Johnson et al. 2002). Dormant buds are kept dormant through a hormonal feedback mechanism from the dominant apical meristems; this includes reduced concentrations of Auxin (IAA), a growth promoter, and high levels of Abscisic Acid (ABA), a growth inhibitor. When the dominant meristem is removed, these hormonal feedbacks are removed; and the dormant buds at the base of the tree become active. They divide and expand to form stump sprouts.

Oaks also have the ability to root graft, which is the growing together of two roots from separate individuals (Lyford 1980). They can often share water, nutrients, and chemical communication through these grafts (Bormann 1966, Kozlowski and Cooley 1990, Loehle and Jones 1990). In certain tree species it has been noted that uncut trees can take the nutrients and carbohydrates stored in the root systems of other trees, which have been harvested or cut, via root grafts. This transport creates a parasitic relationship of the residual trees on the harvested trees root system through the grafts (Bormann 1966, Loehle and Jones 1990). This relationship could decrease the vigor or even inhibit the growth of some stump sprouts in stands with partial harvest treatments.

Disturbance

Disturbance has defined oak systems in the southern Appalachians for thousands of years. The Appalachians have had three types of fire regimes in the past 4000 years. The first being frequent low intensity burning by Native Americans and lightning strikes, the second high intensity burns post harvest by European Americans, and now the era of fire suppression (Brose et al. 2001). Oaks are better adapted to frequent low intensity fires as regeneration because of their large root to shoot ratios, below ground root collars, many root collar buds, prolific sprouting, and relatively long life span (Larsen and Johnson 1998). The era of fire suppression has led to a conversion of these oak forests to more mesic, thin barked, fire-intolerant species. To combat this era of suppression a number of new forms of disturbance have been tried as substitutes for fire. Herbicide as a cost-effective pre-harvest treatment was shown to control undesirable and un-merchantable regeneration (Loftis 1978, 1985). Other disturbances such as mechanical scarification of the seedbed can control competition and promote oak germination and regeneration (Zaczek 2001). Prescribed fires have been used in many oak regeneration scenarios with varying degrees of success (Van Lear and Waldrop 1999).

Silvicultural Systems

Silviculture as defined by Smith et al. (1997) is "the art of producing and tending a forest: the application of knowledge of silvics in the treatment of a forest; or the theory and practice of controlling forest establishment, composition, structure and growth." They also go on to describe how "silviculture is designed to create and maintain the kind of forest that will best fulfill the objectives of the owner and governing society." The following described treatments apply the aforementioned silvics of oak in an attempt to control forest establishment of oak, continued oak composition, and improved conditions for the growth of oak. However some landowner objectives are multiple (according to the 1976 National Forest Management Act) including; continue to keep healthy, diverse Appalachian oak forests while minimizing impacts on the soil, other forest resources, and aesthetics.

This has led to the development of a number of variable retention harvesting systems which can meet the landowner goals while minimizing or alleviating some of the negative aspects commonly associated with clearcutting. These silvicultural systems produce diverse and heterogeneous canopy strata which can provide critical habitat and mimic other successional or seral stages, which some species of concern may prefer or even require (Stoleson 2004). The retained vegetation can provide these species with structural elements for habitat requirements, provide improved microclimate conditions or understory conditions for regenerating target species, and provide energy sources for non-autotrophic organisms in a post harvest environment (Franklin 1997).

Clearcutting is a common form of even-aged management in the southern Appalachians and has been widely accepted as a successful method for oak regeneration on fair to lower quality sites. It is a simple, efficient method requiring only one entry removing the overstory, and disturbs many lower quality sites enough to favor oak regeneration. Many stands that have been clearcut have successfully regenerated to desirable Appalachian hardwood species (Blount et al. 1986, Cook et al. 1996). Clearcuts rely heavily on stump sprout regeneration under the full light conditions created by complete overstory removals. However as is evident from the oak regeneration literature, site quality is a dominant factor affecting the composition of regeneration post harvest. Species conversions away from desirable regeneration can happen on higher quality sites, above upland oak SI_{50} 20-21m, under these full light conditions (Blount et al. 1986, Loftis 1990a, Cook et al. 1996).

A commercial harvest is a common timber harvesting method used throughout all eastern hardwood forests in which the highest quality stems and most desirable species are harvested (Nyland 1992). This harvest method is not a silvicultural practice. It creates two-aged to uneven-aged stands depending on the number of entries and intensity of the harvests. This stand structure is created through retaining those individuals which do not meet the specifications for the initial harvest. This practice is not recognized as a silvicultural or regeneration practice and is often termed high-grading, diameter-limit cutting, or selective harvesting. This form of harvest often leads to undesirable species and poorly formed residuals with reduced growth (Trimble 1971, Fajvan et al. 1998). Stands which have had multiple such harvests are becoming much more common in the Appalachians. Fajvan et. al. (1998) found evidence indicating that 80% of harvests in the state of West Virginia fall into this category. Commercial harvests are appealing because of the reduced aesthetic impact by leaving residuals, and the large economic incentive of only removing those trees with the highest current market values. However these harvests are leading to shifts in species composition away from ecologically and economically valuable species, degrading genetic resources, and reducing growth and yield within these stands.

A leave-tree harvest is an alternative silvicultural treatment to clearcutting. It leaves stand conditions similar to those of a clearcut, but creates more aesthetically pleasing stands. It is also called a deferment cut (Smith et al. 1989). In this system 30-40 reserve trees/ha are left on site forming a two-aged stand. These sparse residuals lead to high light conditions on most of the forest floor, much higher than in a shelterwood method (Smith et al. 1989). Also unlike a shelterwood system these trees are not to be removed. These residuals are usually deferred or left standing as a separate age class from the regeneration until the next rotation.

The residuals do serve a number of functions. They cover unsightly clearcuts with canopy and blend in better with the landscape. They can also provide a reserve seed source and alter regeneration conditions within a sphere of influence (Miller et al. 2006). This method depends on regeneration from low sources, like stump sprouting and advance regeneration, as well as germinating seeds. It is much like a clearcut in terms of the forms and competitive environment of the regeneration. When implemented on areas of higher site quality, more mesic species will out-compete the more xeric oaks species.

A number of concerns arise when releasing trees of this age and size to spatial distributions of this magnitude. These trees have always grown within a canopy and now are being released to the elements. Older trees can succumb more easily to wind-throw, form epicormic branches, and interfere with regeneration (Smith et al. 1989). The shading influence of these reserve trees on regeneration can cause reduced shade intolerant regeneration closer to the reserve trees (Miller et al. 2006). Reserve trees also showed an 88% increase in surface area covered by northern red oak crowns and a 44% increase for yellow-poplar. Such crown expansion greatly increases the influence of these seemingly few reserve trees (Miller et al. 2006).

A shelterwood harvest system is another silvicultural alternative to clearcutting. It is normally a high forest method; defined by the encouragement of seed origin reproduction (Smith et al. 1997). The seedlings that survive will begin to accumulate as advance regeneration. It involves the removal of the mature stand in some series of cuttings. In the case of oaks on poor to moderate sites, it is normally two stages, an initial cut and a final overstory removal. This allows for the establishment of a single cohort of advance regeneration under partial shade conditions, from both seed and sprout origin. Shelterwoods can be used on sites of higher quality, greater than upland oak SI_{50} 20-21m, to recruit advance oak regeneration under a partially harvested canopy. In such cases it will involve three steps.

The first step of a shelterwood on higher quality sites should be an herbicide application which is applied to undesirable species and stems in the mid and understory through basal injection. The objective of the chemical control is to favor the development of advance oak regeneration (Wender 2000). In this sense the herbicide is acting as a disturbance, and increasing light levels to the forest floor favoring oak germination and growth. This treatment can be used in lieu of more expensive timber stand improvement practices such as postharvest felling of undesirable species (Loftis 1985). The herbicide application acts as an early cleaning and release operation eliminating poor form and undesirable competition, therefore, saving the need for more costly cleaning operations later in stand development.

The second stage involves the removal of trees that are of lower crown positions, of lower quality, and are of undesirable species. Problems can occur at this stage if residuals are damaged in felling and skidding, which devalues the most valuable parts of the stand (Johnson et al. 1998). This partial harvest should allow around 30% light penetration to maximize advance oak regeneration growth, though this number may need to be reduced on better sites (Phares 1971, Loftis 1990a). Also if light levels are increased too much and mature canopy tree boles are exposed to light, which can cause epicormic branching, residuals will be devalued (Johnson et al. 1998). The accumulated advance oak regeneration can then be released through the last step.

The final removal harvest is the last step and should be no earlier than 10 years after the initial treatment. This will allow the advance oak regeneration time to produce a root system capable of supporting a shoot large enough to out-compete faster growing intolerant competition (Loftis 1990a). This shade intolerant competition will germinate under the more favorable micro-site conditions created when light levels are maximized by the final overstory removal, but the oak advance regeneration should be well enough established to out-compete these new germinantes.

A group selection harvest is another alternative to clearcutting normally defined to be small openings, no smaller than a fifth of a hectare and not much larger in diameter than twice the height of the adjacent canopy, in order to maximize regeneration diversity (Smith 1981, Nyland 2002). The objective of this method is to continually create and eventually maintain uneven-aged stands of multiple cohorts by replacing small groups with any form of regeneration (Smith et al. 1997). These group openings serve as small clearcuts that are heavily influenced by the surrounding canopy. They are influenced by site quality in much the same ways as the clearcut. If site quality is relatively high, (upland oak SI_{50}> 20m) the recently increased light levels will prompt the germination of more mesic shade intolerant regeneration, which will out compete and overtop oak. In these systems initially oak may not have had time to develop the advance regeneration required for post-harvest success. However, on lower quality sites, group selections are able to create favorable light conditions for the recruitment of advance oak regeneration near the edges of the groups, to release advance regeneration within the groups, and to promote stump sprouts within the groups to successfully regenerate oak. Epicormic branching and wind-throw can be a concern for those trees recently exposed on the edges of the groups.

A pre-harvest herbicide treatment as prescribed by Loftis (1978, 1985) is a cleaning treatment designed to reduce undesirable species post-harvest sprouting, which can compete with regenerating desirable stems. Midstory and understory species that are undesirable and can interfere with the regeneration of desirable species, are treated with a basal application of herbicide. This method has exhibited increases in both the number and quality of desirable stems surviving under canopy conditions (Lorimer et al. 1994).

3. Methods

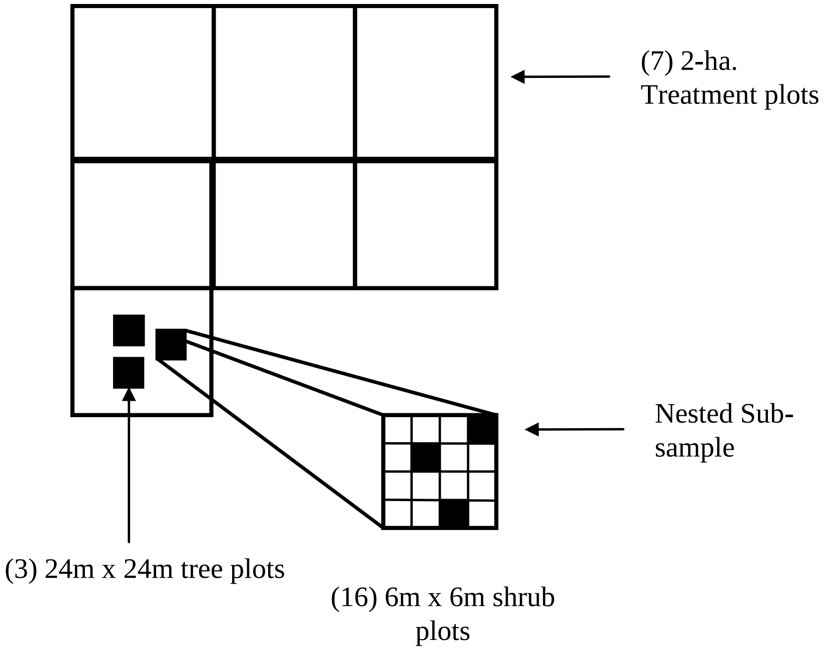
Experimental Design

The study was designed as a randomized complete block. However one site (WV1) was missing two treatments due to space limitations. This required incomplete block analysis to be used. There was no replication at site, which served as the block. Each of the six complete sites are 14 ha with seven 2 ha treatment plots. The incomplete site is 10 ha with five 2 ha treatment plots. Each 2 ha treatment serves as the experimental unit. Within each experimental unit there are 3, 24m x 24m tree sub-plots (Fig. 3.1). The center of the tree plots was established by randomly selecting an azimuth and distance from the center of the treatment square. All of the tree plots are located in the interior of a 22m buffer from the treatment borders. In each tree plot there are 16, 6m x 6m shrub plots. Tree data were collected from the tree sub-plots pre-treatment. Each tree was also tagged and cataloged with an x, y coordinate system for subsequent sampling. The same sub-samples were used to measure the regeneration. Three of the sixteen shrub plots were randomly inventoried from each tree plot to act as sub-samples. Data were also collected on the pre-treatment stands.

Study Sites

Five of the sites were located in the George Washington and Jefferson National Forest of southwestern Virginia (Fig. 3.2). They were named for the Ranger District they were located in at the time the study was established, the Newcastle (NC), Blacksburg (BB1, BB2), and Clinch Ranger (CL1, Cl2) Districts. These districts have been altered since then, but the study site names have not. Two sites were also located on the MeadWestvaco Wildlife and Ecosystem Research Forest (WV1, WV2). The New Castle and Blacksburg sites represent the Ridge and Valley locations while the Clinch and MeadWestvaco sites represent the Appalachian plateau. The sites were chosen for uniformity of stand composition, stand age, stand structure, and geophysiographic

Figure 3.1 Treatment layout as a nested sub-sample with the tree plots and shrub plots located within the larger treatment blocks.



characteristics (Table 3.1). All sites were even-aged, averaging 63-100 years, oak dominated sites with fair to good site qualities ranging from an oak SI_{50} of between 18-24m. They exhibit moderate slopes, occupy a midslope position, and have a southern exposure (Table 3.1).

Treatment Description

1. Control (CT): No silvicultural activity was performed within the stand.
2. Understory and midstory vegetation control (HB): Individual stems in the understory and midstory were treated with herbicide, Garlon 4 (DOW AgroSciences 2007) and Stalker (BASF 2007).
3. Group selection (GP): Three openings of approximately 0.25 ha each were made where all stems greater than 5cm in dbh were harvested. Plans call for re-entry every 20 years.
4. Shelterwood harvest (SW): 12-14 m^2/ha of residual basal area was retained in healthy overstory trees of desirable species during the initial harvest. Plans call

for an overstory removal after 10 years, depending on the growth of advance regeneration.

5. Leave-tree harvest (LT): Approximately 25-45 trees/ha totaling 5 m^2/ha of basal area were retained in healthy overstory trees during the initial harvest. These trees will remain throughout the next rotation creating a two-aged stand.
6. Commercial harvest (CH): Approximately 4-7 m^2/ha of residual basal area was retained in low quality stems of undesirable species.
7. Silvicultural clearcut (CC): All stems greater than 5cm dbh were harvested. However scattered individual trees were retained for wildlife value.

Sampling Protocol

Residual Tree Inventories (Tree Plots)

Prior to treatment, one year post treatment, and four years post treatment, all stems greater than 5m tall in each tree plot were measured, located on grid maps, and tagged at the base. Data collected were: species, location, dbh, crown class, overall crown health, and damage. To monitor residual tree response, these measurements were recorded again for the tagged trees. The following was collected for each tree: date, site, treatment, tree plot, shrub plot, tree tag number, dbh, health code, crown class, number of small (< 3 cm diameter) and large branches (≥ 3 cm diameter) in the first 6m of bole, and basal sprouts.

Regeneration (Shrub Plots)

To answer questions regarding species composition and competitive position in the regeneration, all stems not measured as previous overstory trees were measured in the shrub plots. In the prior research, every stem between 1 and 5m was measured; but as the stand developed, the regeneration has grown out of such parameters. Previously collected data were: species, crown size, origin (seed or stump), and damage. At this time date, site, treatment, tree plot, shrub plot, species, if applicable a former tree number, diameter at ground level (dgl), dbh if applicable, height, crown class, origin, and stump clump number to identify those sprouts originating from a single stump were recorded.

Stump sprouts (Tree Plots)

To further quantify any differences in stump sprout percent and vigor among alternative treatments, all 16 of the shrub plots in each tree plot were inventoried for the clearcut, leave-tree, and shelterwood. Using previous data for the tagged trees, stumps were located and data were recorded on date, site, plot, tree number, species, diameter at ground level (dgl), dbh, height, and crown class within regeneration strata.

Table 3.1 Site Descriptions

											Pre-Treatment	
Site	**County, State**	**Aspect (degrees)**	**Slope %**	**Avg. Ann. Precip (cm)**	**Oak Site Index50 (m)**	**Age years**	**Year of Harvest Completion**	**Years Inventoried**	**Age at measurement**	**QMD (cm)**	**Basal area (m^2/ha)**	**Stems/ha**
BB1	Montgomery, VA	153 ± 19	16 ± 3	101.6	23	100	1995	1993, 2006	11	19.8	25.5	847
BB2	Montgomery, VA	151 ± 14	21 ± 3	101.6	22	99	1996	1995, 2006	10	18.2	26.8	1045
CL1	Wise, VA	149 ± 20	30 ± 3	124.5	18	100	1998	1993, 2007	9	21.1	29.2	839.9
CL2	Wise, VA	108 ± 19	16 ± 3	124.5	20	76	1998	1995, 2007	9	19.2	29.1	1022
NC	Craig, VA	150 ± 16	12 ± 4	113.6	18	62	1996	1995, 2006	10	17.4	24.2	1024
WV1	Randolph, WV	270 ± 7	38 ± 3	113.9	23	73	1997	1996, 2007	10	17.8	35.2	1519
WV2	Randolph, WV	129 ± 11	9 ± 4	113.9	24	63	1998	1997, 2007	9	18.2	32.5	1293

Adapted from Hammond 1997, Hood 2001, Lorber 2002

Table 3.2 Pre-harvest Overstory. Letters represent significant differences.

	Dominant and Codominant		All stems	
	Stems/ha	BA m^2/ha	Stems/ha	BA m^2/ha
Species Group	Mean±SE	Mean±SE	Mean±SE	Mean±SE
Oak	167 ± 18.0 A	13 ± 0.8 A	249 ± 29.0 B	15 ± 0.9 A
Maple	44 ± 5.2 B	3 ± 0.5 B	290 ± 23.2 B	5 ± 0.6 B
Miscellaneous	32 ± 4.1 B	3 ± 0.5 B	139 ± 11.6 C	3 ± 0.5 B
Black cherry-yellow poplar	30 ± 4.6 B	3 ± 0.6 B	87 ± 11.6 D	3 ± 0.6 B
Midstory	29 ± 3.7 B	2 ± 0.2 B	354 ± 29.0 A	3 ± 0.3 B
Sum	302 ± 37	24 ± 2.1	1119 ± 104	30 ± 2.6

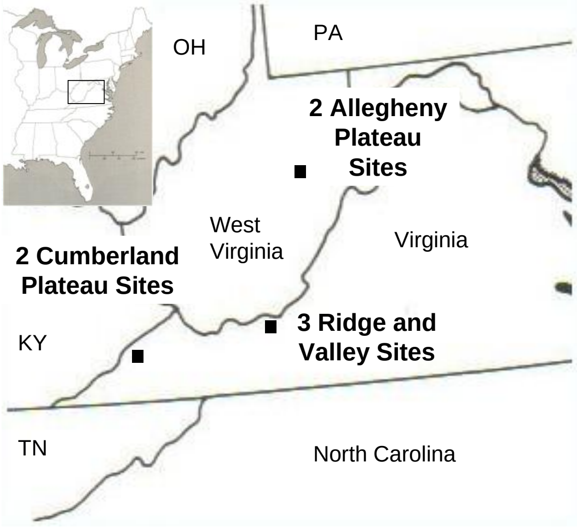


Figure 3.2. Study site locations.

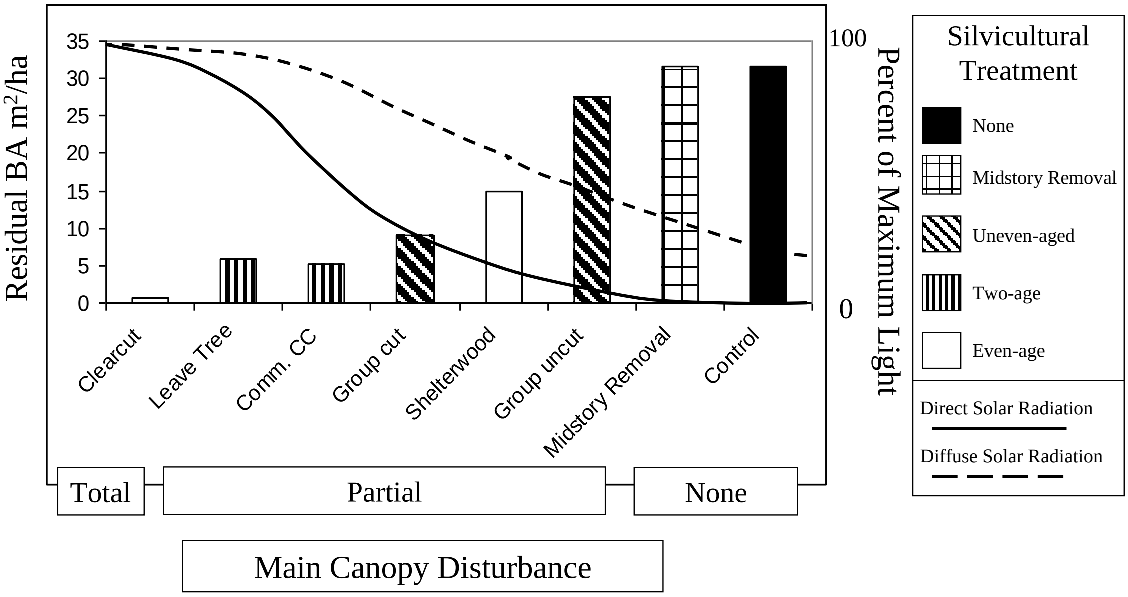


Figure 3.3 Concept model of available light levels (theoretical) to the regeneration among treatments with measured post harvest residual basal areas in each treatment categorized by stand age structure.

4. Data Analysis

Regeneration data were compared among the treatments within species groups. The mixed model analysis of variance (ANOVA) procedure was used with the restricted/residual maximum likelihood (REML) variance estimation method (Fig. 4.1) (Littell et al. 2006, SAS 2006). This model allowed for treatment effects to be considered fixed effects because the treatments are the effects about which inferences are to be made. Site effects represented block effects and were considered random, creating the ‘mixed’ effects model (Littell et al. 2006). The slice option was used to obtain a simple effects test among means (SAS 2006). Least squares means comparisons were used to test differences at a confidence level of α less than 0.05. The response variables were importance value, mean height and density. The slice options were physiographic province, treatment, species group, and origin.

Overstory analysis was done by using a mixed model ANOVA procedure as well with the REML variance estimation method. Treatment effects were again fixed while site effects were random. The response variables were small branches, large branches, and sprouts. Least square means comparisons were used to test for significance at a confidence level of α less than 0.05 (SAS 2006).

Sprouting data were analyzed using a non-parametric one-way ANOVA. The percent of stumps which sprouted were calculated by species group. After an arcsine transformation, these data still violated other ANOVA assumptions of normalcy. Differences were found using Wilcoxon scores and the Kruskal-Wallis test (Ott and Longnecker 2001, SAS 2006). The response variable was the percent of those cut stumps which sprouted by physiographic province and species group, among treatment. An α level of less than 0.05 was used to test significance for all analyses.

Regression analysis was run by species group using residual basal area as the regressor for percent of stumps that sprouted and the number of sprouts per stump as the two response variables (Excel 2003). An α level of less than 0.05 was used to test significance for all analyses. Logistic regression was used to test the influence of dbh on the percent of stumps that sprouted as well.

The number of sprouts per stump was compared within species groups, between physiographic provinces, and among the treatments using a mixed model ANOVA procedure with the REML variance estimation method (Littell et al. 2006, SAS 2006). This model allowed for species group, treatment, and province effects to be considered fixed effects. Site effects represented block effects and were considered random (Littell et al. 2006). The slice option was used to obtain a simple effects test among means for species group, treatment, and province effects. Least squares means comparisons were used to test differences at a confidence level of α less than 0.05.

Figure 4.1. Mixed model ANOVA output.

```
                  The Mixed Procedure
                  Model Information
Data Set                     WORK.LIMIT
Dependent Variable           Height
Covariance Structure         Variance Components
Estimation Method            REML
Residual Variance Method     Profile
Fixed Effects SE Method      Model-Based
Degrees of Freedom Method    Containment

                  Class Level Information
            Class     Levels    Values
       site           7    BB1 BB2 CL1 CL2 NC WV1 WV2
       Trmt           8    CC Ctl GrpC GrpU Herb LT fifty
                                twenty
       sppgrp         5    Maple mids oak othr poplar-cherry

                  Dimensions
             Covariance Parameters             2
             Columns in X                     54
             Columns in Z                      7
             Subjects                          1
             Max Obs Per Subject           46823

                  Number of Observations
             Number of Observations Read           46823
             Number of Observations Used           46823
             Number of Observations Not Used           0
```

```
                  Iteration History
 Iteration  Evaluations -2 Res Log Like   Criterion
  0              1    182867.16964103
  1              2    181801.64104348      0.00000349
  2              1    181801.44234892      0.00000047
  3              1    181801.41796825      0.00000001
  4              1    181801.41740422      0.00000000

                Convergence criteria met.

                The Mixed Procedure
                Covariance Parameter
                        Estimates
                Cov Parm     Estimate
                site           0.1177
                Residual       2.8340

                Fit Statistics
            -2 Res Log Likelihood        181801.4
            AIC (smaller is better)      181805.4
            AICC (smaller is better)     181805.4
            BIC (smaller is better)      181805.3

                Type 3 Tests of Fixed Effects
                      Num     Den
     Effect           DF       DF    F Value     Pr > F
     Trmt              7    47E3     536.34     <.0001
     sppgrp            4    47E3     497.85     <.0001
     Trmt*sppgrp      28    47E3      28.97     <.0001


                                Least Squares Means
                                         Standard
Trmt  Estimate       Error   DF    t Value    Pr > |t|     Alpha

CC     2.3008      0.1322    47E3      17.40      <.0001       0.05
Ctl    0.4328      0.1368    47E3       3.16      0.0016       0.05
GrpC   2.1136      0.1331    47E3      15.88      <.0001       0.05
GrpU   0.8977      0.1330    47E3       6.75      <.0001       0.05
Herb   0.4089      0.1357    47E3       3.01      0.0026       0.05
LT     2.2117      0.1326    47E3      16.67      <.0001       0.05
fifty  1.4919      0.1324    47E3      11.27      <.0001       0.05
twenty 1.9022      0.1324    47E3      14.36      <.0001       0.05

Least Squares Means
```

```
Trmt    Lower       Upper

CC      2.0417      2.5600
Ctl     0.1647      0.7009
GrpC    1.8527      2.3746
GrpU    0.6370      1.1584
Herb    0.1428      0.6750
LT      1.9517      2.4717
fifty   1.2324      1.7514
twenty  1.6426      2.1618
```

5. Effects of Alternative Silvicultural Treatments on Regeneration in the Southern Appalachians

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Abstract

Harvesting practices in the southern Appalachians have moved away from clearcutting in favor of alternative systems. This study investigated the effects of alternative systems, which retain varying numbers of residual trees, on regeneration in Appalachian hardwoods. The treatments included: a clearcut, commercial harvest, leave-tree, shelterwood, group selection, midstory treatment, and an uncut control. The sites included seven stands in Virginia and West Virginia. The stands were even-aged oak dominated Appalachian hardwood stands on medium quality sites with average ages ranging from 63 to 100 years.

Permanent sub-plots were randomly located in each treatment and all overstory trees (>5m tall) were inventoried and tagged prior to harvest. Advance regeneration was also quantified. Harvests occurred between 1995-98. The plots were re-inventoried 9-11 years post-harvest and data were recorded on developing regeneration. Mixed model ANOVA was used to analyze treatment response in six species groups: oak (*Quercus* spp.), maple (*Acer* spp.), black cherry (*Prunus serotina* Ehrh.) yellow-poplar (*Liriodendron tulipifera* L.), miscellaneous, and midstory. Response variables included importance value, and average height and density for all regeneration, and a subset of the tallest 365 stems/ha. Comparisons were made among treatments, species groups, and between regeneration of sprout and seedling origin.

The pre-harvest herbicide treatment reduced the mean height of competing stems in the maple, miscellaneous, and midstory groups, but did not increase the mean density or height of oak. Alternative systems that retained residual overstory trees reduced mean height growth of the regeneration compared to that in the clearcut by at least 0.34-0.74m. Density for the clearcut was similar to those found in the alternative systems. Of the tallest 365 stems/ha, oak regeneration was dominated by taller more numerous stump sprouts. Maple group stump sprouts were also taller in most treatments. Black cherry-yellow-poplar group stump sprouts were competitive but the regeneration was overwhelmingly of seedling origin. The Miscellaneous group was the least affected by treatment, showing reduced growth in some alternative treatments.

Keywords: alternative silviculture; oak regeneration; clearcut; leave-tree; shelterwood; group selection; stump sprouts;

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1. Introduction

Over the past several decades, forest management objectives have become more diverse and complex catering to different wants and needs from both society and landowners. These objectives have forced a change in harvesting methods in the southern Appalachians. The shift has been away from traditional silvicultural methods, such as clearcutting, towards alternative systems which retain variable numbers of trees to meet specific objectives. These goals range from lessening aesthetic impacts to providing structural elements from the previous stands for wildlife food and habitat, ameliorating alterations in the microclimate, and preserving ecosystem types such as oak (*Quercus* spp.) forests and the functions which they have come to serve in the southern Appalachians (Smith et al. 1989, Loftis 1990a, Franklin et al.1997, Miller et al. 2006, McShea et al. 2007).

Conditions at the time currently mature stands established were different than today. Chestnut blight (*Cryphonectria parasitica*), large-scale exploitive harvesting, low herbivory, and frequent fire disturbance created conditions favorable for the establishment of shade intermediate oak species, which comprise the canopy today (Yarnell 1998). Oaks tend to maintain a substantial presence following harvest of stands on poor sites. However studies in the southern Appalachians have demonstrated that under current conditions, treatments which create full-light conditions will not maintain similar amounts of oak on high quality sites (Beck and Hooper 1986, McNab 1988, Loftis 1990b, Cook et al. 1996). The lack of fire has contributed to a species shift away from fire-tolerant oak advance regeneration. Oak is considered to be more xeric, and in the absence of fire, more mesic species such as yellow-poplar (*Liriodendron tulipifera* L.), or more plastic but fire-sensitive species such as red maple (*Acer rubrum* L.) are replacing oak on many sites in the southern Appalachians (Larsen and Johnson 1998, Abrams 1998). The term "mesophication", as applied by Nowacki and Abrams (2008), describes changes in forest management over time which have lead to shifts in understory environments away from xeric high disturbance environments created by Native Americans and later European settlers to shaded, cooler, more mesic environments with little or no disturbance. This is now leading to post-harvest species composition shifts.

Oak reproduction originates from three sources: seedlings, advance regeneration, or stump sprouts. New seedlings that germinate following harvest are frequently overtopped by faster growing competitors (Larsen and Johnson 1998). Sander and others (1971, 1972, 1976, & 1984) and Loftis (1990a) have described the importance of large advance regeneration in maintaining oak in the Missouri Ozarks and the southern Appalachians respectively. Often the accumulation of advance oak regeneration is hindered by the development of shade-tolerant midstory species in the southern Appalachians (Loftis 1985). However, competition from these shade tolerant midstory species can be reduced through the application of herbicide (Loftis 1978, 1985).

Stump sprouting is a more important form of oak regeneration in the southern Appalachians than in other areas (Cook et al. 1996). The quality of trees which result from stump sprouts equals other forms of oak regeneration if stands are properly harvested and stump heights are kept low (Groninger et al. 1998). Additionally, oak stump sprouts are often more competitive than the other two sources of regeneration. Stump sprouts have a large established root system which supports more rapid growth. Commonly, multiple flushes occur, due to stored carbohydrates and an increased ability to obtain resources, which allows the sprouts to be more competitive (Johnson et al. 2002).

The pre-harvest herbicide treatment as prescribed by Loftis (1978, 1985) is a cleaning treatment designed to reduce undesirable species in the understory that compete with desirable stems. In this method, prior to harvest, midstory and understory species that are undesirable and can interfere with the regeneration of desirable species are treated with a basal application of herbicide. This method has been demonstrated to lead to increases in both the number and size of advance regeneration of desirable species (Lorimer et al. 1994).

Clearcutting has been a widely accepted practice for successfully regenerating oak on lower quality sites (Blount et al. 1986, Cook et al. 1996). Clearcuts rely heavily on stump sprouts under full light conditions created by complete overstory removals (Fig. 5.1). However, site index is an important factor influencing oak regeneration (Loftis 1990a, Cook et al. 1996). In the absence of large advance oak regeneration, clearcutting of mature oak dominated stands on high quality sites in the southern Appalachians leads to a shift in species composition toward yellow-poplar (Beck and Hooper 1986, Blount et al. 1986, Loftis 1990a, Cook et al., 1996).

Oak regeneration problems in Appalachian hardwood forests are exacerbated by the preponderance of diameter limit harvesting. This form of harvest retains poor quality stems and promotes the regeneration of less desirable species. Fajvan et al. (1998) found that 80% of the harvests in West Virginia were implemented as diameter limit cuts. This form of harvest also tends to create stands where residual trees have poor form and reduced growth (Trimble 1971, Fajvan et al. 1998).

The leave-tree system has been proposed as a more aesthetically pleasing alternative to clearcutting which creates similar regeneration conditions (Fig. 5.1). Also called a deferment cut, it is a two-age method in which few individual stems (30-40 reserve trees/ha) are retained through the next rotation, creating two distinct age classes (Nyland 2002, Smith et al. 1989). The residuals serve a number of functions including improved aesthetics, wildlife habitat, and a seed source (Miller et al. 2006). As residual trees respond to opened conditions, they can succumb to wind-throw and interfere with the regeneration environment. In West Virginia, residual northern red oak (*Q. rubra* L,) trees showed an 88% increase in surface area covered by crowns while yellow-poplar showed a 44% increase (Miller et al. 2006). Such crown expansion greatly increases the influence of these seemingly few reserve trees

The shelterwood system is another alternative method to clearcutting. A multistage shelterwood system has been developed for Appalachian hardwood stands that enables large advance oak regeneration to develop (Sander 1979, Loftis 1990b). The key to the successful recruitment of large advance oak regeneration is to increase light levels at the forest floor to approximately 30% of full sunlight through removal of the shade tolerant midstory and light cuttings in the lower canopy (Fig. 5.1) (Loftis 1990b). The final removal of the overwood occurs when the oak advance regeneration is large enough to out compete faster growing shade intolerant species (Loftis 1990a).

The group selection system is another alternative to clearcutting that creates an uneven-aged stand. It is generally recommended that the diameter of the openings not exceed twice the height of the adjacent canopy in order to maximize regeneration diversity (Smith 1981, Nyland 2002). The size of the group opening that is appropriate to regenerate oak depends on site quality and height of the trees. On high quality sites (SI_{50} > 20m), openings larger than this will promote the establishment of more mesic shade intolerant species which will out compete and overtop oak. On lower quality sites, group selections are able to create conditions favorable for oak regeneration (Fig. 5.1).

The objectives of this study were to quantify the differences in the regeneration among the treatments in terms of growth, species composition, and origin. We hypothesized that residual trees will shade the regeneration impeding growth rates because even few trees which expand there crowns can have an influence over regeneration therefore not truly mimicking a clearcut. Also intolerant species will be more prevalent in those treatments which maximize light levels to the regeneration, and stump sprouts will be more competitive than seedling or advance origin regeneration.

2. Methods and Materials

Study Sites

Seven sites supporting stands of mature hardwoods in the Appalachians were selected for this study. The sites were mature oak dominated Appalachian hardwood stands with tolerant midstory species occupying lower canopy strata (Table 5.1). Each site served as a block in the experimental design and treatments were not replicated at an individual site. Two sites were located on Cumberland Plateau in the Clinch Ranger District of the Jefferson National Forest in southwest Virginia (CL1, CL2) (Fig. 5.2). These stands averaged between 76 and 100 years old with about 35 m^2/ha of basal area in around 1100 stems/ha over 5 m in height. Slopes averaged between 16-30%, aspects were southeast, precipitation averaged 125 cm distributed throughout the year, and July temperatures averaged 21^oC and December temperatures averaged 3^oC (Lorber 2002). The soil series is mapped as Muskingum. It is a fine-loamy, mixed, semiactive, mesic Typic Dystrudept, moderately deep, well drained, and moderately preamble channery silt loam (NRCS 2008). Oak site index ranged from SI_{50} 18-20 m.

Two sites were located on the Allegheny Plateau in West Virginia on land owned by the MeadWestvaco Corporation (WV1, WV2) (Fig. 5.2). These stands averaged between 63 and 73 years old with around 35 m^2/ha of basal area in around 1400 stems/ha over 5 m in height. Slopes averaged between 9-38%, aspects were west and southeast, precipitation averaged 113 cm distributed throughout the year, and July temperatures averaged 21^oC and December temperatures averaged -2^oC (Lorber 2002). The soil series were mapped as a complex of Gilpin-Dekalb series, an ultisol and entisol of similar origin; Gilpin a Fine-loamy, mixed, active, mesic Typic Hapludult and Dekalb a Loamy-skeletal, siliceous, active, mesic Typic Dystrudept. Both series are moderately deep, acidic, and well to excessively well drained (NRCS 2008). Oak site index ranged between SI_{50} 23-24 m.

Three sites were located in the Ridge and Valley in the Eastern Divide Ranger District of the Jefferson National Forest in southwest Virginia (BB1, BB2, NC) (Fig. 5.2). These stands averaged between 62 and 100 years old with around 26 m^2/ha of basal area in around 1000 stems/ha over 5 m in height. Slopes averaged between 12-21%, aspects were southeast, precipitation averaged 105 cm distributed throughout the year, and July temperatures averaged 21^oC and December temperatures averaged 2^oC (Lorber 2002). The soil series were mapped as a complex of Berk-Weikert. Berks series is a loamy-skeletal, mixed, active, mesic Typic Dystrudept, while Weikert is a Lithic Dystrudept. Both of these soils are well drained but the Lithic, Weikert is shallow where as the Typic, Berks is moderately deep (NRCS 2008). Oak site index ranged between SI_{50} 18-23 m.

Experimental Design

The study was designed as a randomized incomplete block design with 7 treatment plots at the 7 different sites. Sites served as blocks and treatments were not replicated at an individual site. At one site (WV1), two treatments were not installed because of space limitations. Each of the six complete sites are 14 ha, with seven 2 ha treatment plots. The incomplete site used 10 ha with five 2 ha treatment plots. Each 2 ha treatment serves as the experimental unit. Within each experimental unit, there are three 24m x 24m tree plots which serve as sub-plots (Fig. 5.3). The tree plots were randomly located within the treatment plot at least 22m from the plot boundary to prevent any edge effects. Each of the three tree plots was divided into sixteen 6m x 6m shrub plots.

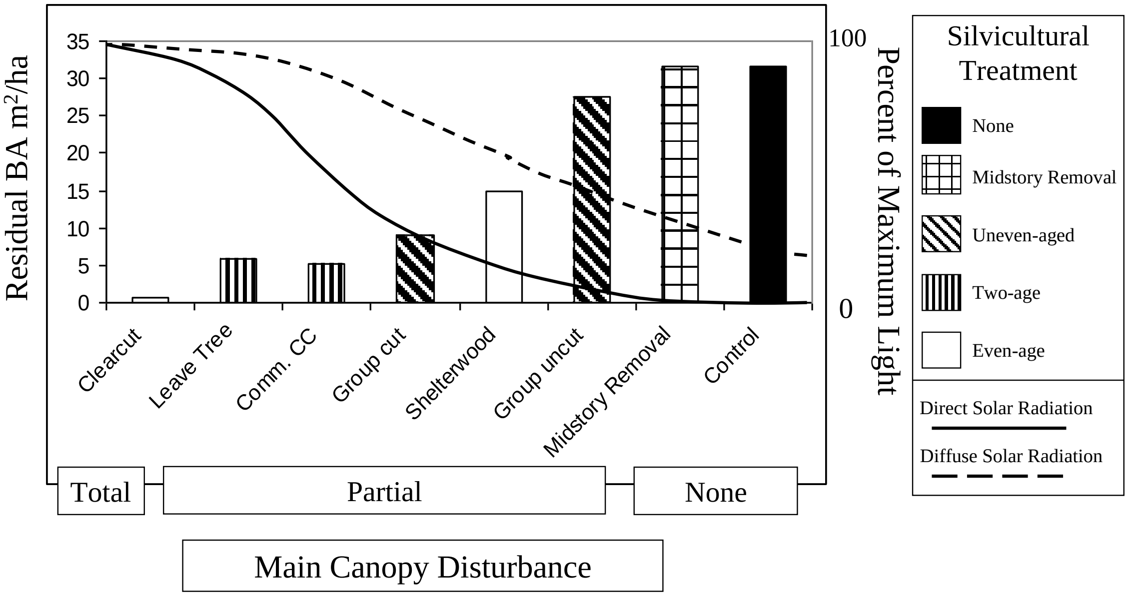

Figure 5.1 Concept model of available light levels (theoretical) to the regeneration among treatments with measured post harvest residual basal areas in each treatment categorized by stand age structure.

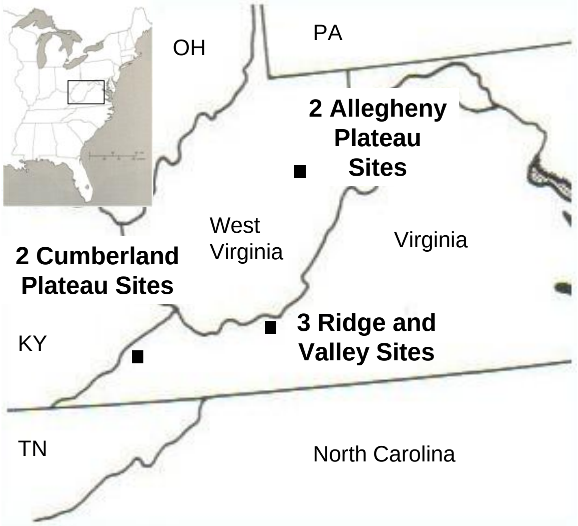

Figure 5.2 Study site locations.

Table 5.1. Stand conditions by site and original overstory composition, basal area (m^2/ha), and density (stems/ha) of all stems greater than 5m in height, by species group.

Site	County, State	Aspect (degrees)	Slope %	Avg. Ann. Precip (cm)	Oak Site Index50 (m)	Age years	Year of Harvest Completion	Age at measurement	Basal Area (m^2/ha)						Desnity (stems/ha)					
									All oak spp.	cherry-poplar	maple	Misc. spp.	Midstroy spp.	Total	All oak spp.	cherry-poplar	maple	Misc. spp.	Midstroy spp.	Total
BB1	Montgomery, VA	153 ± 19	16 ± 3	101.6	23	100	1995	11	22.9	1.6	1.4	1.5	1.2	28.6	401	44	207	127	187	966
BB2	Montgomery, VA	151 ± 14	21 ± 3	101.6	22	99	1996	10	23.0	2.5	2.5	1.5	3.3	32.7	313	123	260	115	472	1283
NC	Craig, VA	150 ± 16	12 ± 4	113.6	18	62	1996	10	20.3		0.9	0.1	2.5	23.7	649		61	24	360	1094
CL1	Wise, VA	149 ± 20	30 ± 3	124.5	18	100	1998	9	20.2	0.4	5.2	3.1	6.4	35.3	233	10	324	147	303	1017
CL2	Wise, VA	108 ± 19	16 ± 3	124.5	20	76	1998	9	18.3	0.9	8.0	2.2	5.7	35.1	201	14	426	197	406	1244
WV1	Randolph, WV	270 ± 7	38 ± 3	113.9	23	73	1997	10	12.8	3.9	6.7	2.6	4.0	30.0	153	89	423	155	474	1294
WV2	Randolph, WV	129 ± 11	9 ± 4	113.9	24	63	1998	9	4.4	8.0	13.0	11.0	3.2	39.4	42	167	574	239	603	1625

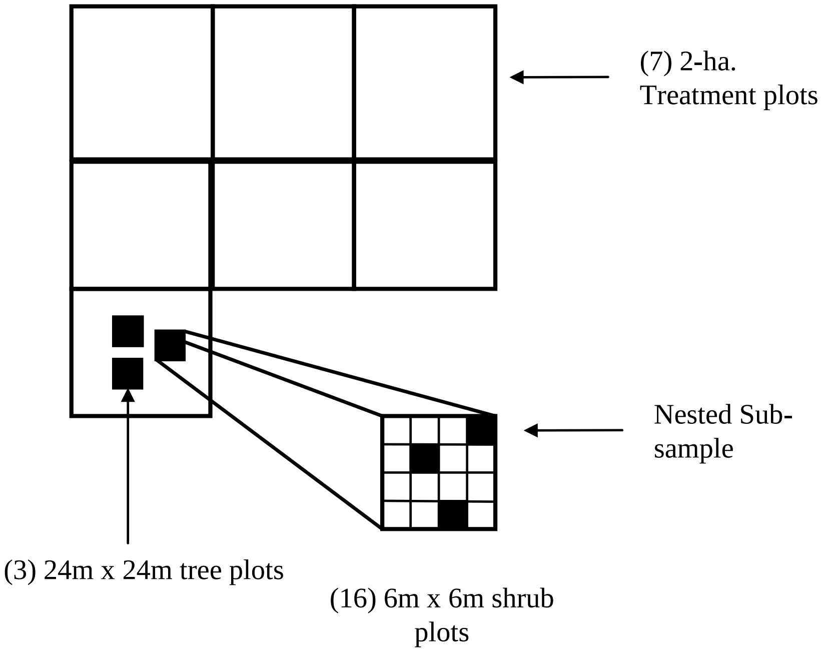

Figure 5.3. Treatment layout as a nested sub-sample with the tree plots and shrub plots located within the larger treatment plots.

Table 5.2. Residual basal area (m^2/ha) one year after harvest for all of the tree plots from which data were collected. Missing values indicate either no treatment was applied at that site, or the treatment basal area was not consistent with the target.

	Treatment									
	CC		CH		LT		SW		GP (cut)	
Site	Mean BA m^2/ha	[n]	Mean BA m^2/ha	[n]	Mean BA m^2/ha	[n]	Mean BA m^2/ha	[n]	Mean BA m^2/ha	[n]
BB1	1.3	[2]	3.5	[3]	2.9	[3]	15.9	[3]	2.5	[3]
BB2	0.0	[3]	3.2	[3]	3.8	[3]	14.3	[2]	0.0	[3]
NC	0.7	[2]	2.4	[3]	3.1	[3]	8.0	[3]	3.1	[3]
CL1	2.6	[3]	6.0	[3]	7.2	[3]	14.8	[3]	3.1	[3]
CL2	0.9	[3]	10.1	[3]	-		20.1	[2]	2.0	[3]
WV1	0.0	[3]	-		3.1	[3]	8.6	[1]	0.0	[3]
WV2	0.0	[3]	8.3	[3]	7.1	[3]	17.0	[2]	0.0	[3]
All	0.8	[19]	5.6	[18]	4.5	[18]	14.2	[16]	1.5	[21]

Treatments

1. Control (CT): No silvicultural activity was performed within the stand.
2. Understory and midstory vegetation control (HB): Individual stems in the understory and midstory were treated with herbicide, Garlon 4 (DOW AgroSciences 2007) and Stalker (BASF 2007).
3. Group selection (GP): Three openings of approximately 0.25 ha each were made where all stems greater than 5cm in dbh were harvested. Plans call for re-entry every 20 years.
4. Shelterwood harvest (SW): 12-14 m^2/ha of residual basal area was retained in healthy overstory trees of desirable species during the initial harvest. Plans call for an overstory removal after 10 years, depending on the growth of advance regeneration.
5. Leave-tree harvest (LT): Approximately 25-45 trees/ha totaling 5 m^2/ha of basal area were retained in healthy overstory trees during the initial harvest. These trees will remain throughout the next rotation creating a two-aged stand.
6. Commercial harvest (CH): Approximately 4-7 m^2/ha of residual basal area was retained in low quality stems of undesirable species.
7. Silvicultural clearcut (CC): All stems greater than 5cm dbh were harvested. However scattered individual trees were retained for wildlife value.

All treatment harvests were done operationally by the landowners using the best management practices required for each site. Each treatment was implemented on a 2 ha area at each site. Treatments were implemented between August 1997 and March 1998 at CL1 and CL2, between May 1997 and September 1998 at WV1 and WV2, and between November 1995 and June 1996 at BB1, BB2, and NC.

Sampling

Prior to harvest each tree in the tree plot greater than 5m in height was measured. Each tree was tagged and cataloged with an x, y coordinate system for subsequent sampling, dbh, condition, and species were recorded. Three of the 16 6m x 6m shrub plots were randomly chosen and regeneration less than 5m in height was measured; species, height, and diameter at ground level (dgl) were recorded.

Following harvest, residuals in the individual sub-plots in each treatment were inventoried. Residual basal area in several of the sub-plots at various locations fell outside of the established treatment targets due to their random placement prior to harvest (Table 5.2). All three of the plots in the LT at CL2 were located in a streamside management zone, consequently residual basal area was much greater than the targets (Table 5.2). Residual basal area at two SW plots at WV1 were well below the targets (Table 5.2). In the CC at BB1 and NC, large wildlife trees were in the plots. Individual sub-plots that fell outside the target basal area range for the treatments were dropped from the analysis because they did not accurately reflect the designated treatment (Table 5.2).

During the summers of 2006-2007, 9-11 years after harvest, the plots at each site were measured again. All regeneration in the three 6m x 6m shrub plots was measured. The data collected were species, original tree number if it was a stump sprout, dgl, dbh, height, crown class within the regeneration strata, origin whether it was a seedling or stump sprout, and a number was given to each stump clump if more than one sprout originated from a single stump. In the GP treatments, additional plots were installed in areas which fell both within the harvested areas and outside areas that were not harvested. The data used in this study were limited to the plots located in the harvested areas of the group treatment.

It was impractical to investigate the effects of the treatments on all 30 species found at the sites. Therefore six species groups were created to simplify the analysis. The first group was the oak group including chestnut (*Q. prinus* L.), northern red, scarlet (*Q. coccinea* Muenchh) white (*Q. alba* L.), and black oak (*Q. velutina* Lam.). The maple group included red and sugar maple (*Acer saccharum* Marsh.). The black cherry (*Prunus serotina* Ehrh.)-yellow-poplar group combine two species which share similar responses to harvest and replace oak on higher quality sites. The miscellaneous group represented other competitive overstory species including Fraser magnolia (*Magnolia fraseri* Walter), basswood (*Tilia americana* L.), tree-of-heaven (*Ailanthus altissima* (Mill.) Swingle), white ash (*Fraxinus americana* L.), green ash (*Fraxinus pennsylvanica* Marsh.), cucumbertree (*Magnolia acuminata* (L.) L), eastern white pine (*Pinus strobus* L.), mockernut hickory (*Carya alba* (L.) Nutt.), pignut hickory (*Carya glabra* (Mill.) Sweet), and bitternut hickory (*Carya cordiformis* (Wangenh.) K). The midstory and short lived species group including striped maple (*Acer pensylvanicum* L.), downy serviceberry (*Amelanchier arborea* (Michx. f.)), sweet birch (*Betula lenta* L.), American chestnut (*Castanea dentata* (Marsh.) Borkh.), flowering dogwood (*Cornus florida* L.), American beech (*Fagus grandifolia* Ehrh.), hophornbeam (*Ostrya virginiana* (Mill.) K. Koch), sourwood (*Oxydendrum arboreum* (L.) DC.), pin cherry (*Prunus pensylvanica* L. f.), black locust (*Robinia pseudoacacia* L.), and sassafras (*Sassafras albidum* (Nutt.) Nees).

Importance value was calculated as a sum of relative dominance, relative density, and relative frequency among species groups within each treatment. Relative dominance was the percent of the total basal area a species occupied, relative density was the percent of the total density occupied by a species, and relative frequency was the percent of plots in which a species was found.

3. Statistical Analysis

Regeneration was compared among the treatments within species group. A mixed model analysis of variance (ANOVA) was used with the restricted/residual maximum likelihood (REML) variance estimation method (Littell et al. 2006, SAS 2006). This model allowed for treatment effects to be considered fixed effects. Sites which served as the blocks were considered random effects creating the mixed model (Littell et al. 2006). The slice option was used to obtain simple effects test among means. Least squares means comparisons were used to test differences at a confidence level of α less than 0.05. The response variables were importance value, height, and density. The slice options were physiographic province, treatment, species group, and origin.

4. Results

Table 5.3. Analysis of all of the regeneration by mean density (stems/ha) and height (m) among treatments 9-11 years after harvest. Letters represent differences among treatments (α < 0.05).

Treatment	Stems/ha Mean±SE		Height (m) Mean±SE	
CC	6058 ± 521	B	2.09 ± 0.031	A
CH	6532 ± 625	AB	1.60 ± 0.029	C
LT	8218 ± 987	AB	1.75 ± 0.027	B
SW	6290 ± 615	AB	1.35 ± 0.025	D
GP	7783 ± 840	AB	1.68 ± 0.028	BC
HB	9177 ± 1465	A	0.21 ± 0.005	E
CT	8113 ± 1224	AB	0.32 ± 0.009	E

Table 5.4. Analysis of the control (CT) and herbicide (HB) treatments regeneration mean height (m) and density (stems/ha) 9-11 years after harvest. Letters represent differences between treatments (α < 0.05).

Species group	Treatment	Height (m) Mean±SE		Stems/ha Mean±SE
Oak	CT	0.21 ± 0.013		61.4 ± 18.9
	HB	0.16 ± 0.006		83.5 ± 15.2
Maple	CT	0.17 ± 0.009	A	145.6 ± 31.8
	HB	0.12 ± 0.004	B	176.7 ± 45.6
Black Cherry-Yellow-poplar	CT	0.34 ± 0.076		6.9 ± 1.7
	HB	0.26 ± 0.055		10.9 ± 4.9
Miscellaneous	CT	0.93 ± 0.063	A	20.4 ± 5.3
	HB	0.71 ± 0.052	B	20.3 ± 3.8
Midstory	CT	0.56 ± 0.009	A	72.1 ± 14.0
	HB	0.35 ± 0.015	B	80.8 ± 14.1

Initial data analysis focused on all of the regeneration within each treatment by species group (Table 5.3). The first investigation compared the HB treatment with the CT to determine if eliminating the midstory increased the number and size of the advance regeneration (Table 5.3). There were no differences in the total stem densities or height between the CT and HB. Examination of the various species groups showed no differences in the densities between these two treatments (Table 5.4). There were, however, reduced heights in the HB treatment in the maple, miscellaneous, and midstory species groups (Table 5.4).

Among the harvesting treatments there were no differences in mean densities of the regeneration. Density of the regeneration varied from 6058 stems/ha in the CC to 8218 stems/ha in the LT (Table 5.3). There were differences in the mean heights of the regeneration. The CC had the tallest regeneration with a mean of 2.1m, followed by the LT at 1.75m, and GP at 1.68m. The LT was taller than the CH at 1.6m which was similar to the GP. These were followed by the SW at 1.35m. (Table 5.3)

There were no differences among treatments in importance value for the oak or miscellaneous species groups (Table 5.5). However as light levels increased, the maple group's importance decreased from a mean of 1.78 in CT to 0.98 in the CH and 1.09 in the CC. As light levels increased, the black cherry-yellow-poplar group's importance increased from a mean of 0.06 in the CT to 0.84 in the CH (Table 5.5).

Further investigations were concerned with the most competitive regeneration in the harvesting treatments. These were made within the species groups based on mean height and density differences among treatments. Only the tallest 365 stems/ha were included in these data to evaluate the most competitive regeneration that is likely to form the future main canopy (Fig. 5.4 & 5.5). This number was based on the original density of upper canopy trees at these sites, and the density of trees in a mature, fully stocked upland central hardwood stand, with an average tree diameter between 22-30 cm (Roach and Gingrich 1968). For this analysis, the midstory group was removed. It was assumed that these species, though they currently are competitive, will drop out of canopy positions as the stem exclusion phase continues and stands reach maturity. Analysis was also run on the tallest 200 and 500 stems/ha to see if there were any relative differences among the treatments within species group across different sample sizes (Table. 5.6 & 5.7).

Analysis based on the tallest 365 stems/ha had many interesting results (Fig. 5.4 & 5.5). The data were further broken down into stump sprout origin, or seedling and advance origin regeneration. It was evident based on the mean height analysis for the oak species group that stump sprout mean heights were taller in every treatment by 1-3m. Overall mean heights of the oak regeneration were greatest in the LT at 7.8m and the CC at 7.3m, followed by the CH at 6.1m, then the GP at 5.5m, and lastly the SW at 4m. In all of the treatments, stump sprouts were a larger proportion of the competitive oak regeneration (Fig. 5.5). Between 48-77 stems/ha were of stump sprout origin while only 20-34 stems/ha were seedling origin. However, overall there were no differences among treatments in the density of competitive oak regeneration with all treatments having between 79-99 competitive stems/ha.

The maple stump sprouts were taller than seedlings by 1-2.7m in all of the treatments except the CC (Fig. 5.4). The mean heights for maple ranged from 7.4m in the CC and 7.5m in the LT, to 6.1m in the CH, 6.4m in the GP, and 5.6m in the SW. The highest regeneration densities for the maple group were in the GP with 161 stems/ha, equally represented by seedlings and stump sprouts (Fig. 5.5). The CC with 83 stems/ha, LT with 107 stems/ha, and SW with 74 stems/ha were similar, with the CC and SW having more stump sprouts 54-64 stems/ha, than seedling 17-19 stems/ha. The SW was also similar to the CH in overall density, which had the lowest, 64 stems/ha, for the maple group.

The black cherry-yellow-poplar group had the tallest overall regeneration (Fig. 5.4). Stump sprouts, when present, were very competitive. The tallest regeneration in the CC which averaged 8m and the SW at 8.1m were stump sprouts, while the GP which averaged 8.3m had taller seedlings (Fig. 5.4). Stump sprouts were also taller in the LT but the overall mean height of 6.5m was lower than the other treatments. The height of the black cherry-yellow-poplar regeneration in the CH (6.7m) was similar to the LT, but seedlings were taller than stump sprouts. In terms of mean density, all of the treatments had more seedlings than stump sprouts except the CC, which had similar numbers (Fig.

Table 5.5. Analysis of importance value means, within species group, and among treatments, 9-11 years after harvest. Letters represent differences among treatments ($\alpha < 0.05$). Treatments below partial lines are those that included no overstory removal.

		Importance Value	
Species Group	Treatment	Mean±SE	
Oak	CC	0.99 ± 0.36	
	CH	0.63 ± 0.26	
	LT	0.96 ± 0.33	
	SW	0.89 ± 0.29	
	GP	0.69 ± 0.24	
	HB	0.70 ± 0.28	
	CT	0.67 ± 0.30	
Maple	CC	1.09 ± 0.22	B
	CH	0.96 ± 0.21	B
	LT	1.28 ± 0.24	AB
	SW	1.20 ± 0.20	B
	GP	1.68 ± 0.25	AB
	HB	1.46 ± 0.42	AB
	CT	1.78 ± 0.28	A
Black cherry-yellow-poplar	CC	0.52 ± 0.17	AB
	CH	0.84 ± 0.30	A
	LT	0.43 ± 0.21	AB
	SW	0.53 ± 0.16	AB
	GP	0.28 ± 0.10	BC
	HB	0.17 ± 0.12	C
	CT	0.06 ± 0.03	C
Miscellaneous	CC	0.48 ± 0.20	
	CH	0.57 ± 0.22	
	LT	0.33 ± 0.12	
	SW	0.45 ± 0.13	
	GP	0.35 ± 0.09	
	HB	0.70 ± 0.20	
	CT	0.50 ± 0.19	

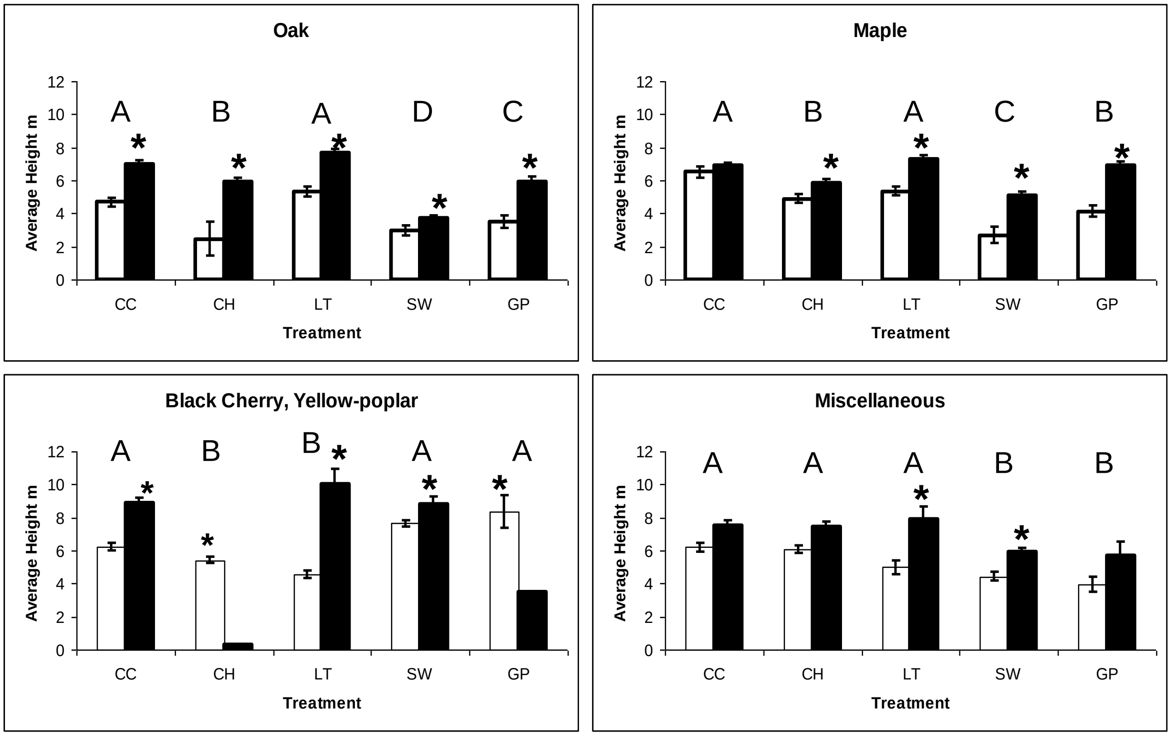

Figure 5.4. Comparison within species group of mean regeneration height (m) from among the tallest 365 stems/ha. Letters represent differences among overall treatment means (α<0.05). Comparison within the treatments between mean height (m) of stump sprout and seedling origin regeneration differences are represented with asterisks (α<0.05).

■ Stump Sprouts
□ Seedlings

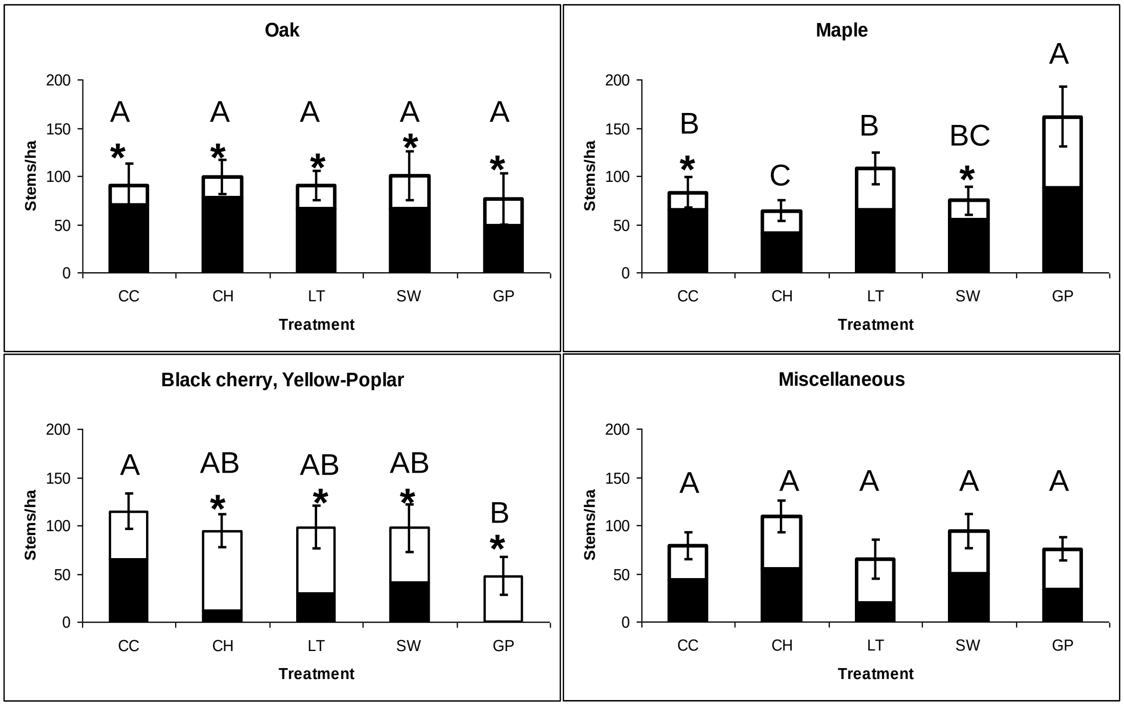

Figure 5.5. Mean density (stems/ha) from the tallest 365 stems/ha compared among treatments within species group. Letters represent differences among overall treatment means (α<0.05). Comparison within the treatments between mean density (stems/ha) of stump sprout and seedling origin regeneration differences are represented with asterisks (α<0.05).

■ Stump Sprouts
□ Seedlings

5.5). The CH with 114 stems/ha had a higher mean density than the GP with 50 stems/ha. All of the other treatment stem densities fell between these two means.

The species in the miscellaneous category were taller in the CC at 7.5m, CH at 7.3m, and the LT at 7.4m than the SW at 5.5m and GP at 5.7m (Fig. 5.4). The LT and SW had taller stump sprout means by 1.5-3m while the other treatments had similar height means between origin. All of the treatments had similar densities, 64-108 stems/ha, as well as similar densities between origin (Fig. 5.5).

Comparison of the tallest 200 stems/ha to the tallest 365 stems/ha revealed no differences for the oak group (Table 5.6). The red maple group results were similar for height, but stem density differences were no longer significant. The black cherry-yellow-poplar group results for height differed revealing the GP to be taller than the SW and CC. Also the difference in density between the GP and CC was no longer apparent. The miscellaneous group results differed with the LT mean height dropping below the CC and CH, and a difference was found in density between the GP, and the CH and SW, where no difference was present in the 365 stems/ha data. The tallest 500 stems/ha analysis had no differences compared to the tallest 365 stems/ha for the oak group (Table 5.7). The maple group had differences in the LT and SW densities compared to the other treatments. The black cherry-yellow-poplar group density had no difference between the CC and GP, but there was a difference between the CH and GP. The miscellaneous group LT height dropped below the CC and CH.

5. Discussion

In accordance with previous work, these data indicate that on fair quality sites oak regeneration is competitive in clearcuts as well as partial harvest systems which retain variable numbers of residuals (Blount et al. 1986, Loftis 1990a, Cook et al., 1998). However this study quantified the dependence of oak on stump sprouts for competitive post harvest regeneration in all of these treatments, for this region. In each treatment, oak stump sprouts were more competitive and had higher densities than other forms of regeneration (Fig. 5.4 & 5.5). This critical component must be properly managed if oak is to perpetuate as a strong component of these stands. With the exception of the LT, in

Table 5.6. Analysis of the tallest 200 stems/ha within species groups among the harvesting treatments by average height (m) and density (stems/ha) 9-11 years after harvest. Letters represent differences among treatments α < 0.05.

		Height (m)		Stems/ha	
Species Group	Treatment	Mean±SE		Mean±SE	
Oak	CC	7.29 ± 0.27	A	53.7 ± 13.2	A
	CH	5.92 ± 0.30	B	52.5 ± 17.6	A
	LT	8.13 ± 0.25	A	43.1 ± 8.1	A
	SW	3.86 ± 0.19	D	64.9 ± 15.9	A
	GP	5.52 ± 0.29	C	35.8 ± 9.7	A
Maple	CC	7.74 ± 0.18	A	48.2 ± 9.5	A
	CH	6.27 ± 0.28	B	38.4 ± 13.5	A
	LT	7.44 ± 0.22	A	60.0 ± 8.1	A
	SW	5.64 ± 0.27	C	42.7 ± 9.0	A
	GP	5.85 ± 0.33	B	60.8 ± 9.6	A
Black cherry-yellow-poplar	CC	7.69 ± 0.24	B	50.9 ± 9.3	A
	CH	6.36 ± 0.29	C	59.6 ± 12.1	A
	LT	6.48 ± 0.43	C	39.4 ± 9.5	A
	SW	8.31 ± 0.23	B	54.8 ± 11.9	A
	GP	10.83 ± 0.84	A	45.3 ± 7.9	A
Miscellaneous	CC	7.84 ± 0.22	A	45.7 ± 6.9	AB
	CH	7.38 ± 0.22	A	64.2 ± 9.1	A
	LT	6.14 ± 0.53	B	48.7 ± 18.1	AB
	SW	5.32 ± 0.26	B	57.3 ± 11.8	A
	GP	5.39 ± 0.57	B	34.0 ± 6.8	B

Table 5.7. Analysis of the tallest 500 stems/ha within species groups among the harvesting treatments by average height (m) and density (stems/ha) 9-11 years after harvest. Letters represent differences among treatments α < 0.05.

		Height (m)		Stems/ha	
Species Group	Treatment	Mean±SE		Mean±SE	
Oak	CC	5.91 ± 0.16	A	100.2 ± 22.4	A
	CH	5.31 ± 0.18	B	106.0 ± 38.1	A
	LT	6.37 ± 0.22	A	95.5 ± 14.6	A
	SW	3.08 ± 0.13	D	115.2 ± 28.8	A
	GP	3.91 ± 0.28	C	83.1 ± 16.7	A
Maple	CC	6.09 ± 0.16	A	95.6 ± 15.0	B
	CH	4.98 ± 0.18	B	52.3 ± 7.2	C
	LT	6.22 ± 0.16	A	115.4 ± 17.7	AB
	SW	4.18 ± 0.19	C	87.2 ± 16.4	B
	GP	5.08 ± 0.20	B	149.5 ± 22.8	A
Black cherry-yellow-poplar	CC	6.86 ± 0.19	A	96.5 ± 18.9	AB
	CH	4.79 ± 0.16	B	155.6 ± 29.0	A
	LT	4.72 ± 0.23	B	108.0 ± 27.3	AB
	SW	7.55 ± 0.23	A	83.7 ± 23.5	AB
	GP	7.66 ± 0.75	A	56.2 ± 10.6	B
Miscellaneous	CC	6.49 ± 0.16	A	82.4 ± 14.1	A
	CH	5.85 ± 0.20	A	103.6 ± 18.3	A
	LT	4.73 ± 0.32	B	100.6 ± 28.1	A
	SW	4.59 ± 0.17	B	127.5 ± 20.3	A
	GP	4.39 ± 0.37	B	85.9 ± 14.4	A

the presence of residuals there were reductions in oak regeneration height growth among the alternative treatments compared to the clearcut.

The results for the pre-harvest herbicide did not support those of Loftis (1985) and Lorimer et al. (1994) in terms of an increase in the number of desirable stems; however, similar results were seen in the reduction of undesirable stems (Table 5.4). However, the understory herbicide treatment did not remove trees from the lower portions of the main canopy, which would be needed to increase light levels to 30% of full sunlight. Consequently, little advance oak regeneration developed.

The density data in Table 5.3 indicate that the regeneration in the CC has already undergone canopy closure and is beginning to move through the stem exclusion phase. This was evident at all of the sites. The alternative systems have done so as well and should soon follow this trend. Alternative systems, which retained residual trees, slowed mean height growth of all of the regeneration compared to the CC (Table 5.3.). The LT and GP harvesting systems were the tallest alternatives. These systems were designed as aesthetic alternatives to large clearcuts, which would closely mimic the regeneration conditions created by a clearcut (Smith et al. 1989, Smith 1981). These data suggest that conditions may be close, but not similar; and as a result; growth is reduced in these systems. The CH data showed reduced regeneration growth compared to the LT, which had a similar residual basal area, further indicating this form of harvest reduces growth of subsequent stands compared to silvicultural systems (Trimble 1971, Fajvan et al. 1998). The SW had the shortest regeneration of the canopy disturbance treatments.

The importance value data reflected the shade tolerance of species groups as a response to treatment (Table 5.5). The shade tolerance of the maple group was evident as importance values gradually decreased with increased basal area removal and elevated light levels (Fig. 5.1). The decrease in the maple group was replaced by an increase of the shade intolerant black cherry-yellow-poplar group.

The maple species, like the oak group, showed reduced growth in the alternative systems, with the exception of the LT. Maple appeared to be most prolific in the GP, which could have been a reflection on group size, though according to Smith (1981), the group sizes were large enough to regenerate intolerant regeneration normally seen in a clearcut. This was indicated by the height growth response of the black cherry-yellow-poplar group. Maple stump sprouts proved to be the most prolific form of regeneration in the CC and SW, and tallest in the CH, LT, SW, and GP. This would indicate that as red maple continues to establish and invade mature oak stands on these sites, and increase in importance as a midstory and sub-canopy component, stump sprouting may increase in importance as a form of regeneration (Abrams 1998). As this trend continues in the absence of historic disturbances such as fire, a pre-harvest herbicide treatment which did reduce the height of maple group stems may become more important.

The black cherry-yellow-poplar group seedlings showed an increased importance in these stands. This was evident in the CH and GP where seedlings were the tallest form of regeneration, and all treatments, with the exception of the CC, where seedlings were the most common form of regeneration. Furthering this concern for the next rotation, stump sprouts had greater height growth responses in the CC, LT, and SW and similar densities in the CC. All treatments had similar black cherry-yellow-poplar total stem densities except for the CC, which was higher than the GP. These data indicate that this species group will increase in importance, through seedling regeneration, relative to pre-harvest conditions; and once established these species have the ability to perpetuate through competitive stump sprouts.

The miscellaneous group's height growth was tallest in the lowest residual basal area treatments, the CC, CH, and LT followed by the SW and GP. Density however was unaffected by treatment. Each treatment also had equal numbers of stump sprout and seedling origin regeneration. This species group appears to be increasing in importance from the previous stands at the expense of oak.

Overall variable retention harvests on fair quality sites in the southern Appalachians do not seem to have a large impact on regeneration density 9-11 years after harvest. However, overall height growth was reduced among the alternative systems as compared to the clearcut. All species groups also showed height growth reductions to some degree from clearcutting to alternative systems. This should be taken into consideration when projecting post harvest stand development and rotation length. At this stage, it is not clear which trees will comprise the canopy of the next stand; but by eliminating those species not normally capable of reaching canopy positions and only looking at the top 365 stems/ha, it appears that stump sprouts still hold a competitive advantage in all treatments for oak, and in at least two treatments for the other species groups. Stump sprouts were also proven to be oak's most numerous form of regeneration for all of the treatments. The influence of these alternative treatments on stump sprouting and the competitive ability of the sprouts after partial harvest needs to be quantified. It does appear as though oak will decline in importance in the next stand. It appears as though maple species stump sprouts, and to some degree seedlings, are replacing it, as well as a strong seedling component of black cherry and yellow poplar. Other competitive species are also increasing and showed few affects from alternative treatments. However, it is not certain how to predict which species will fall behind as competition becomes more intense through the stem exclusion phase, and which species will prove to be successful competitors into the future.

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6. Effects of Alternative Silviculture on Stump Sprouting in the Southern Appalachians

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Abstract

As management objectives in the southern Appalachians have changed, so too have management practices. Stump sprouts are among the most competitive forms of regeneration for a number of key species in this region, especially the oaks (*Quercus* spp.). The effects of alternative silvicultural systems on stump sprouts are not known. We evaluated the impact of three silvicultural systems: a clearcut, leave-tree, and shelterwood, on stump sprouting. These treatments were implemented in seven stands in Virginia and West Virginia over two physiographic provinces. The stands were even-aged oak dominated Appalachian hardwood stands on fair quality sites with average ages ranging from 62 to 100 yrs.

Permanent plots were randomly located in each stand, and all overstory trees (>5m tall) were inventoried and tagged prior to harvest. Regeneration was also quantified. Harvests occurred between 1995-98. The plots were re-inventoried 9-11 years post-harvest and data were recorded on stump sprouts. Species were placed into six groups: the red oak (*Quercus* spp.), chestnut oak (*Q. prinus* L.), white oak (*Q. alba* L.) and hickory (*Carya* spp.), red maple (*Acer rubrum* L.), mixed mesic; and midstory groups. A non-parametric one-way ANOVA analyzed the percent of those cut stumps that sprouted and a mixed model ANOVA was used to analyze the numbers of sprouts per stump among treatment by species group. These response variables were also tested against residual basal area using regression analysis.

Physiographic province was found to influence stump sprouting. In the Ridge and Valley, the clearcut had the highest sprouting rates for the red oak (60%), chestnut oak (77%), white oak-hickory (26%), and midstory (33%) species groups. Red maple sprouting was highest in the leave-tree (67%) in this province. Sprouting of all oak groups was lower in the Appalachian Plateau, where the mixed mesic group sprouted best in the shelterwood (55%). Partial harvesting systems decreased sprouting in both provinces. They also reduced the number of sprouts per stump for the red oak group and red maple. The mixed mesic and midstory groups were only reduced in the Ridge and Valley. Regression analysis showed residual basal area to be a negatively correlated predictor of stump sprout percent for the red oak group, chestnut oak, and red maple, and also for the number of chestnut oak sprouts per stump ($\alpha < 0.05$). All oak sprouting was shown to be reduced by 2% for every $1 m^2/ha$ increase in residual basal area.

Keywords: Variable retention harvest; oak regeneration; clearcut; leave-tree; shelterwood; stump sprouts.

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1. Introduction

Over the past several decades, changes in forest management objectives have forced a change in silvicultural systems in the southern Appalachians. These objectives have become more diverse and complex catering to different wants and needs from both society and landowners. The move has been away from clearcutting towards alternative methods which retain variable numbers of stems to meet objectives related to improving aesthetics, providing structural elements from the previous stands for wildlife food and habitat, reducing alterations in the microclimate, and preserving oak (*Quercus* spp.) ecosystem types (Smith et al. 1989, Loftis 1990a, Franklin et al.1997, Miller et al. 2006, McShea et al. 2007).

Maintaining oak forests and the critical functions which they serve in the southern Appalachians has proven to be difficult. Oak is considered a keystone species in the southern Appalachians. Its high commercial value has become important to the region and is recognized world wide (Appalachian Hardwood Manufactures 2007). After chestnut blight (*Cryphonectria parasitica*) eliminated American chestnut (*Castanea dentata* (Marsh.) Borkh.) as an overstory component in the southern Appalachians, oaks have become the most important hard mast producing species (McShea et al. 2007).

Oak regeneration originates from three sources: seedlings, advance regeneration, or stump sprouts. Newly established seedlings are frequently overtopped by faster growing competitors and rarely contribute to future stand composition at rotation age (Larsen and Johnson 1998). In contrast, large advance oak regeneration can grow fast enough following harvest to remain in the upper canopy of the developing stand, thus contributing to merchantable volume in the future. Sander and others (1971, 1972, & 1984) and Loftis (1990b) have described the ability of advance regeneration to perpetuate oak following harvest in the Missouri Ozarks and the southern Appalachians respectively. However accumulation of advance oak regeneration is hindered by the development of tolerant midstory species in many stands in the southern Appalachians, which can impede post harvest oak development (Loftis 1985). Stump sprouts are an important source of regeneration for oak because stump sprouts will grow fast enough to successfully compete during the stem exclusion phase following canopy closure. Stump sprouts have a large established root system which often supports more rapid growth and multiple flushes from stored carbohydrates and an increased ability to obtain resources (Johnson et al. 2002). Stump sprouting has been found to be more important in the southern Appalachians than other areas (Cook et al. 1996). The quality of trees which result from stump sprouts equals other forms of oak regeneration if stands are properly harvested and stump heights are kept low (Groninger et al. 1998).

A concern in many mature Appalachian hardwood stands is that oak's sprouting ability has been shown to drastically decrease with increasing parent tree age and diameter in clearcuts. In a southern Indiana clearcut, Weigle and Johnson (1998) found large decreases in first year sprouting probabilities for white oak (*Q. alba* L.) once trees become older than 50 years or larger than 20 cm dbh. However there are important differences in sprouting abilities among species. Chestnut oak (*Q. prinus* L.) sprouting did not decrease until age 100 years or a dbh over 30 cm, while black oak (*Q. velutina* Lam.) declined after 70 years or a dbh over 30 cm. Northern red (*Q. rubra* L.) and scarlet oak (*Q. coccinea* Muenchh.) sprouting dropped after 70 years or a dbh greater than 30 cm. Cook et al. (1998) also investigated a number of studies which showed regional variations in the initial sprouting probabilities for a number of oak species across size, age, site quality, and season of harvest. Generally stump sprouting decreases as site quality increases, but trees harvested during the dormant season have shown higher rates of sprouting (Johnson et al. 2002, Cook et al. 1998).

Clearcutting was promoted as the most effective and efficient form of timber management in this region in the 1960's (Roach and Gingrich 1968). However frequently oak regeneration has been inadequate following clearcuts on higher quality sites (Beck and Hooper 1986, Loftis 1990b, Cook et al. 1996). This led to the development of alternative silvicultural systems designed to manipulate the light regime and foster the development of advance oak regeneration (Loftis 1990a). However these alternative systems involve multiple entries and depend on recruiting advance regeneration, which in most cases can take multiple years for proper implementation and success. Other alternatives were developed to mimic clearcut conditions while leaving just enough residual trees to lessen the aesthetic impacts of clearcuts (Smith et al. 1989).

However the effects of these alternative systems on stump sprouting is not known (Johnson et al. 2002). The objectives of this study were to quantify the effects of alternative silvicultural systems and different residual basal areas on stump sprouting percents and the number of sprouts per stump in the southern Appalachians. We predicted a greater proportion of stump sprouting in the treatments with fewer residuals trees, and stump sprouts would be more vigorous, in terms of the number of sprouts per stump, in the treatments with fewer residual trees.

2. Methods and Materials

Study Sites

Seven sites in the southern Appalachians were included in this study. These sites supported mature Appalachian hardwood stands with tolerant midstory species occupying the lower canopy strata (Table 6.1). Two sites were located on Cumberland Plateau in the Clinch Ranger District of the Jefferson National Forest in southwest Virginia (CL1, CL2) (Fig. 6.1). These stands averaged between 76 and 100 years old with about 35 m^2/ha of basal area in around 1100 stems/ha over 5 m in height. Slopes averaged between 16-30%, aspects were southeast, precipitation averaged 125 cm distributed throughout the year, and July temperatures averaged 21^oC and December temperatures averaged 3^oC. The soil series is mapped as Muskingum. It is a fine-loamy, mixed, semiactive, mesic Typic Dystrudept, moderately deep, well drained, and moderately preamble channery silt loam (NRCS 2008). Oak site index ranged from SI_{50} 18-20 m.

Two sites were located on the Allegheny Plateau in West Virginia on land owned by the MeadWestvaco Corporation (WV1, WV2) (Fig. 6.1). These stands averaged between 63 and 73 years old with around 35 m^2/ha of basal area in around 1400 stems/ha over 5 m in height. Slopes averaged between 9-38%, aspects were west and southeast, precipitation averaged 113 cm distributed throughout the year, and July temperatures averaged 21^oC and December temperatures averaged -2^oC. The soil series were mapped as a complex of Gilpin-Dekalb series, an ultisol and entisol of similar origin; Gilpin a Fine-loamy, mixed, active, mesic Typic Hapludult and Dekalb a Loamy-skeletal, siliceous, active, mesic Typic Dystrudept. Both series are moderately deep, acidic, and well to excessively well drained (NRCS 2008). Oak site index ranged between SI_{50} 23-24 m.

Three sites were located in the Ridge and Valley in the Eastern Divide Ranger District of the Jefferson National Forest in southwest Virginia (BB1, BB2, NC) (Fig. 6.1). These stands averaged between 62 and 100 years old with around 26 m^2/ha of basal area in around 1000 stems/ha over 5 m in height. Slopes averaged between 12-21%, aspects were southeast, precipitation averaged 105 cm throughout the year, and July temperatures averaged 21^{o}C and December temperatures averaged 2^{o}C. The soil series were mapped as a complex of Berk-Weikert. The Berks series is a loamy-skeletal, mixed, active, mesic Typic Dystrudept, while Weikert is a Lithic Dystrudept. Both of these soils are well drained but the Lithic, Weikert is shallow where as the Typic, Berks is moderately deep (NRCS 2008). Oak site index ranged between SI_{50} 18-23 m.

Treatments

The three treatments included a shelterwood harvest (SW) where a target 12-14 m^2/ha of residual basal area was retained during the initial harvest in healthy canopy trees of desired species (Table 6.2). This created a partial light environment on the forest floor designed to encourage the recruitment of advance regeneration of intermediately shade tolerant species such as oak. Initial plans called for an overstory removal between ages 5-10 depending on the growth of advance regeneration. A leave-tree harvest (LT) where approximately 25-45 trees/ha totaling a target 5 m^2/ha of basal area were retained during the initial harvest in desirable healthy overstory stems (Table 6.2). These trees will remain throughout the next rotation creating a two-aged stand. The third treatment was a silvicultural clearcut (CC) where all stems greater than 5 cm dbh were harvested (Table 6.2). This created full light conditions to the regeneration. Other treatments were also located at these sites but stump sprouting was not investigated. These treatments were included in a larger study of the impacts of harvesting on ecosystem diversity and function. All treatment harvests were done operationally by the landowners using the best management practices required for each site. Each treatment was implemented on a 2 ha area at each site. Treatments were implemented between August 1997 and March

Table 6.1. Stand conditions by site and original overstory composition, basal area (m^2/ha) and density (stems/ha), of all stems >5m in height, by species group.

Site	County, State	Aspect (degrees)	Slope %	Avg. Ann. Precip (cm)	Oak Site Index50 (m)	Age years	Year of Harvest Completion	Age at measurement	Basal Area (m^2/ha)					Desnity (stems/ha)				
									All oak spp.	red maple	Mixed Mesic spp.	Midstory spp.	Total	All oak spp.	red maple	Mixed Mesic spp.	Midstory spp.	Total
BB1	Montgomery, VA	153 ± 19	16 ± 3	101.6	23	100	1995	11	24.2	1.3	1.8	1.2	28.6	187	73	506	200	966
BB2	Montgomery, VA	151 ± 14	21 ± 3	101.6	22	99	1996	10	24.0	2.2	3.2	3.3	32.7	472	185	404	222	1283
NC	Craig, VA	150 ± 16	12 ± 4	113.6	18	62	1996	10	20.4	0.9		2.5	23.7	360		673	61	1094
CL1	Wise, VA	149 ± 20	30 ± 3	124.5	18	100	1998	9	20.3	5.2	3.5	6.4	35.3	303	158	234	322	1017
CL2	Wise, VA	108 ± 19	16 ± 3	124.5	20	76	1998	9	19.2	8.0	2.2	5.7	35.1	406	191	221	426	1244
WV1	Randolph, WV	270 ± 7	38 ± 3	113.9	23	73	1997	10	12.8	6.4	6.8	4.0	30.0	474	307	153	360	1294
WV2	Randolph, WV	129 ± 11	9 ± 4	113.9	24	63	1998	9	4.4	8.2	23.7	3.2	39.4	545	689	42	262	1538

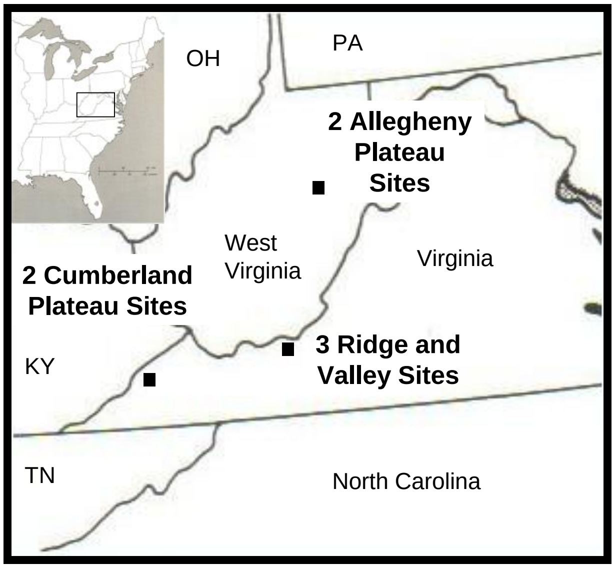


Figure 6.1. Study site locations.

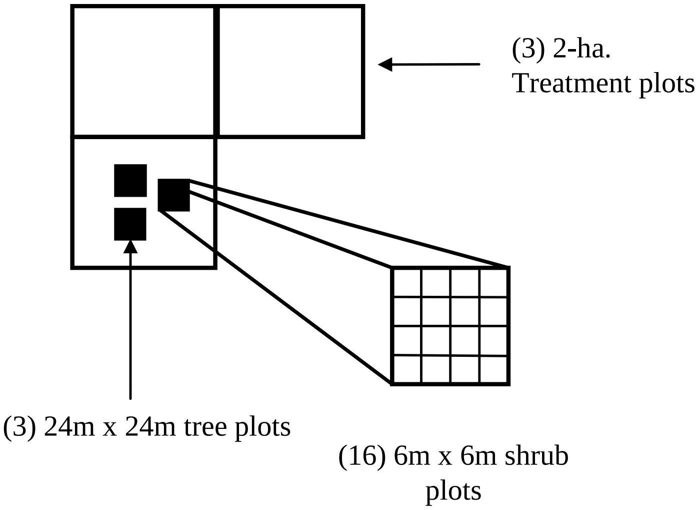


Figure 6.2. Treatment layout as a nested sub-sample with the tree plots and shrub plots located within the larger treatment blocks.

1998 at CL1 and CL2, between May 1997 and September 1998 at WV1 and WV2, and between November 1995 and June 1996 at BB1, BB2, and NC.

Study Design and Sampling

The study was established as a randomized complete block design. Each of the seven sites served as a block with each 2 ha treatment plot serving as an experimental unit. Within each experimental unit there were 3, 24m x 24m tree plots which served as sub-samples (Fig. 6.2). Prior to harvest the tree plots were randomly located within the 2 ha treatment plot, except that tree plots were located a minimum of 22m from the border to minimize edge effect. Each tree plot was subdivided into 16, 6m x 6m shrub plots.

Prior to harvest each tree in the tree plot greater than 5m in height was measured. Each tree was tagged and cataloged with an x, y coordinate system for subsequent sampling, dbh, condition, and species were recorded. During the summers of 2006-2007, 9-11 years after harvest, the sub-plots at each site were measured again. Data were collected on all residual trees within the tree plots including date, tag number, species, dbh, health code, and crown class. A full inventory of the stumps was also completed at this time within each tree plot. Previously tagged trees that were cut during harvest were located and the following data were collected on the stumps which sprouted: tree number, species, sprout diameter at ground/stump level (dgl), dbh, height, and crown class of all sprouts.

Residual basal area in several of the sub-plots at various locations fell outside of the established treatment criteria. All three of the plots in the LT at CL2 were located in a streamside management zone, consequently residual basal area was much greater than planned (Table 6.2). Residual basal area at two SW plots at WV1 were well below the targets (Table 6.2). In the CC at BB1 and NC, several large trees were retained as wildlife trees in the plots. Individual sub-plots that fell outside the target basal area range for the treatments were not used in the analysis comparing the 3 treatments because they did not accurately reflect the designated treatment. These data were used, however, in the regression analysis as they fit into the spectrum of different residual basal areas.

Twenty-eight species with stump sprouts were identified in the plots. Because of the large number of species, they were combined into six groups according to abundance in the plots, similarities in silvical characteristics, and economic importance. Chestnut oak (n = 411) and red maple (*Acer rubrum* L.) (n = 881) were abundant enough to form individual species groups. Red oak species of the *Erythrobalanus* group, including northern red oak, black oak, and scarlet oak were pooled into a single red oak group (n = 528). White oak and hickory, including pignut hickory (*Carya glabra* (Mill.) Sweet), mockernut hickory (*Carya alba* (L.) Nutt.), and bitternut hickory (*Carya cordiformis* (Wangenh.) K), were grouped (n = 242). The mixed mesic species group included yellow-poplar (*Liriodendron tulipifera* L.), black cherry (*Prunus serotina* Ehrh.), cucumbertree (*Magnolia acuminata* (L.) L), fraser magnolia, (*Magnolia fraseri* Walter), sugar maple (*Acer saccharum* Marsh.), basswood (*Tilia americana* L.), white ash (*Fraxinus americana* L.), and green ash (*Fraxinus pennsylvanica* Marsh.) (n = 733). A final group included those species which are midstory species, not normally occupying an upper canopy position, and those species which are short lived and drop out of stands relatively early in the stem exclusion phase (n = 1539). These species include striped maple (*Acer pensylvanicum* L.), downy serviceberry (*Amelanchier arborea* (Michx. f.)), sweet birch (*Betula lenta* L.), American chestnut, flowering dogwood (*Cornus florida* L.), American beech (*Fagus grandifolia* Ehrh.), hophornbeam (*Ostrya virginiana* (Mill.) K. Koch), sourwood (*Oxydendrum arboreum* (L.) DC.), pin cherry (*Prunus pensylvanica* L. f.), black locust (*Robinia pseudoacacia* L.), and sassafras (*Sassafras albidum* (Nutt.) Nees).

3. Statistical Analysis

The percent of stumps that sprouted was calculated for each plot. After an arcsine transformation these data did not result in a normal distribution required for analysis of variance (ANOVA) (Ott and Longnecker 2001). Therefore these data were analyzed using a non-parametric one-way ANOVA. The differences among treatments were compared using Wilcoxon scores and the Kruskal-Wallis test (Ott and Longnecker 2001, SAS 2006). The response variable was the percent of those cut stumps which sprouted by physiographic province and species group among treatment. An α level of less than 0.05 was used to test significance for all analyses.

The number of sprouts per stump was compared within species groups, between physiographic provinces, and among the treatments using a mixed model ANOVA procedure with the restricted/residual maximum likelihood (REML) variance estimation method (Littell et al. 2006, SAS 2006). This model allowed for species group, treatment, and province effects to be considered fixed effects. Site effects represented block effects and were considered random, creating the mixed model (Littell et al. 2006). The slice option was used to obtain a simple effects test among means for species group, treatment, and province effects. Least squares means comparisons were used to test for differences at an α level of less than 0.05.

Regression analysis was run by species group using residual basal area as the regressor (Excel 2003). The response variables were the percent of stumps that sprouted and the number of sprouts per stump. Logistic regression was used to test the influence of dbh on the percent of stumps that sprouted as well.

4. Results

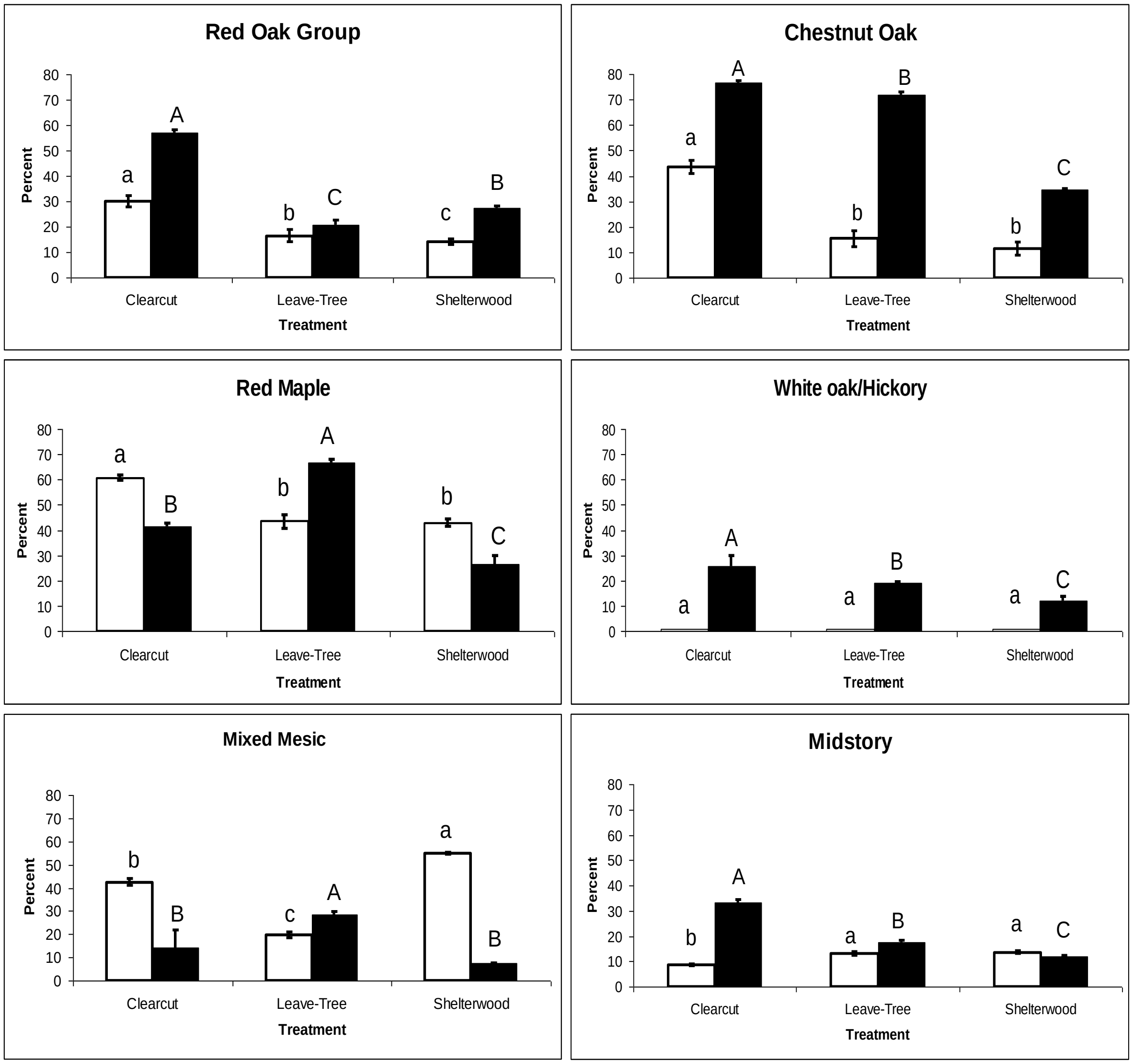
Species, treatment, and physiographic province were all found to be significant factors affecting stump sprouting percent and the number of sprouts per stump 9-11 years post harvest (Table 6.3). The results of the logistic regression investigating the influence of dbh on sprouting were not significant. There was little variation in dbh as these stands were even-aged and had very restricted diameter distributions. Sprouting in the red oak, chestnut oak, and white oak/hickory groups was greater in the Ridge and Valley (RV) than in the Appalachian Plateau (AP) (Table 6.3). The differences between physiographic provinces was most drastic in the white oak/hickory group where 6% or fewer of the stumps sprouted on the AP. In contrast, 19 to 36% of the stumps in the white oak/hickory group sprouted in the RV. In both provinces, the proportion of stumps that sprouted was less in the LT and SW compared to the CC. For example on the AP, in the red oak group 42% of the stumps in the CC sprouted where only 23% of the stumps in the LT or SW sprouted (Table 6.3). Likewise in the RV, 60% of the red oak stumps sprouted in the CC but only 30% and 33% of the stumps in the LT and SW sprouted.

Table 6.2. Residual basal area (m^2/ha) one year after harvest for all of the tree plots from which data were collected. Missing values indicate either no treatment was applied at that site, or the treatment basal area was not consistent with the target.

	Treatment					
	CC		LT		SW	
Site	Mean BA m2/ha	[n]	Mean BA m2/ha	[n]	Mean BA m2/ha	[n]
BB1	1.3	[2]	2.9	[3]	15.9	[3]
BB2	0.0	[3]	3.8	[3]	14.3	[2]
NC	0.7	[2]	3.1	[3]	8.0	[3]
CL1	2.6	[3]	7.2	[3]	14.8	[3]
CL2	0.9	[3]			20.1	[2]
WV1	0.0	[3]	3.1	[3]	8.6	[1]
WV2	0.0	[3]	7.1	[3]	17.0	[2]
All	0.8	[19]	4.5	[18]	14.2	[16]

Table 6.3. Percent of all cut stumps which had surviving sprouts 9-11 years after harvest. Letters signify differences among treatment means within species groups and physiographic combinations ($\alpha < 0.05$).

		Province					
		Plateau			Ridge and Valley		
Spp.	Treatment	Percent ± SE	[n]		Percent ± SE	[n]	
Red oak Group	CC	41.6 ± 1.40	[72]	A	60.0 ± 1.14	[90]	A
	LT	22.7 ± 1.27	[66]	B	29.8 ± 1.76	[77]	B
	SW	23.5 ± 1.05	[86]	B	32.8 ± 1.25	[134]	B
Chestnut Oak	CC	50.0 ± 3.65	[44]	A	78.5 ± 1.32	[107]	A
	LT	24.1 ± 2.82	[29]	B	73.5 ± 2.37	[87]	B
	SW	17.8 ± 2.01	[28]	C	39.6 ± 1.04	[116]	C
Red maple	CC	65.1 ± 0.62	[264]	A	49.3 ± 1.08	[73]	B
	LT	51.8 ± 0.99	[162]	B	69.6 ± 1.42	[66]	A
	SW	52.2 ± 0.27	[268]	B	31.2 ± 2.50	[48]	C
White oak/ Hickory	CC	0.0	[24]		36.2 ± 3.43	[45]	A
	LT	0.0	[16]		25.5 ± 2.00	[85]	B
	SW	6 ± 1.51	[18]	A	19.4 ± .74	[54]	C
Mixed mesic	CC	48.7 ± 0.42	[190]	B	20.2 ± 6.33	[15]	B
	LT	28.4 ± 0.84	[222]	C	31.0 ± 3.68	[29]	A
	SW	61.2 ± 0.33	[250]	A	11.3 ± 2.34	[27]	C
Midstory	CC	32.1 ± 0.67	[264]	A	39.9 ± 1.10	[223]	A
	LT	28.1 ± 0.10	[433]	B	23.1 ± 0.85	[160]	B
	SW	31.3 ± 0.12	[233]	A	15.0 ± 0.63	[226]	C


Red Oak Group

Chestnut Oak

Red Maple

White oak/Hickory

Mixed Mesic

Midstory

Figure 6.3. Percent of stumps which produced dominant and codominant sprouts 9-11 years after harvest by species group among treatments. Capital letters signify a difference (α<0.05) among treatment means in the Ridge and Valley. Lower case letters signify a difference (α<0.05) among treatment means on the Appalachian plateau.

■ Ridge and Valley
□ Plateau

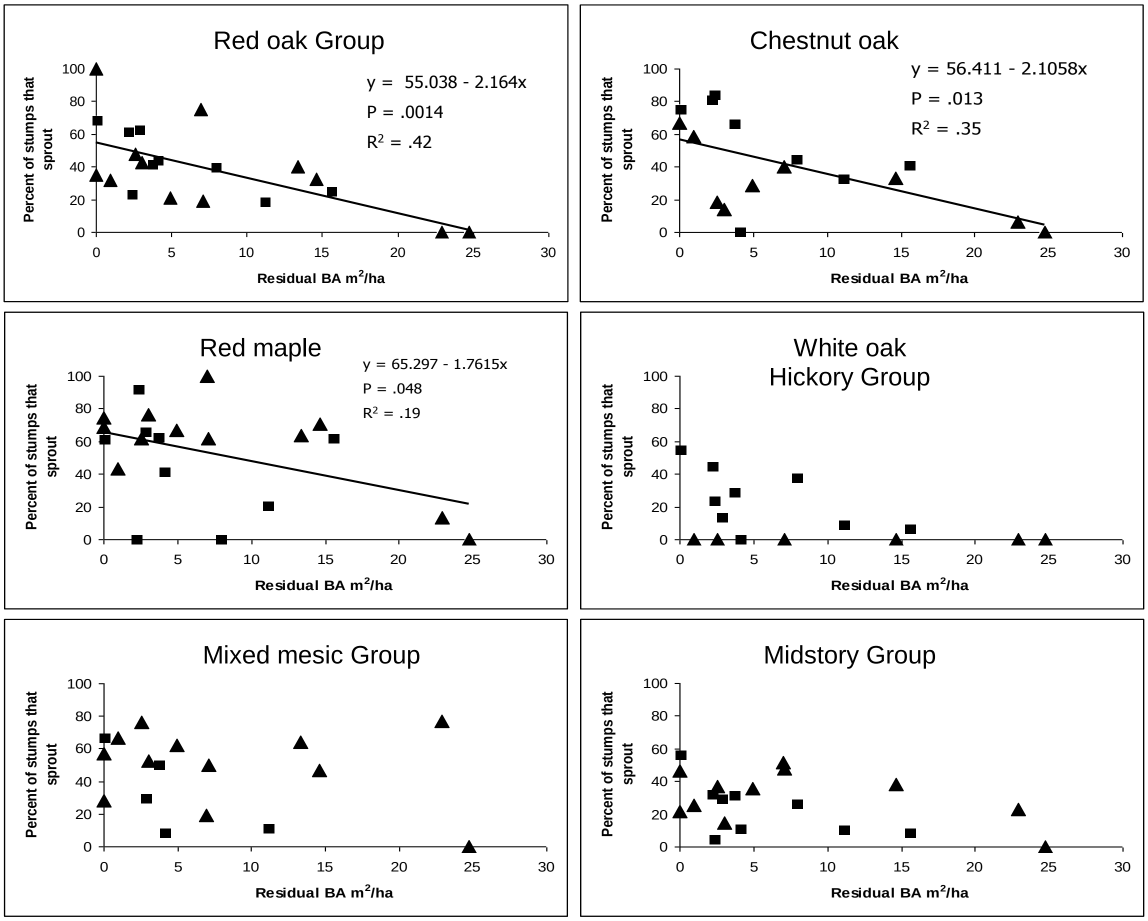


Figure 6.4. Regression of percent of stumps that sprouted 9-11 years after harvest by residual basal area (m^2/ha) for species groups. Trend lines, equations, and R^2 values are displayed for significant ($\alpha<0.05$) relationships. Each point represents the data for a 24m x 24m tree plot.

▲ Plateau

■ Ridge and Valley

Table 6.4. Mean number of total sprouts, and codominant and dominant sprouts per clump, for those stumps which sprouted, by species group compared among treatments and between physiographic province 9-11 years after harvest. Letters signify differences among treatment means within a species group (α < 0.05). Asterisks signify differences between physiographic province means within species group(α < 0.05).

		Total number of stumps		Average Number of Sprouts per Stump		Average Number of Dominant and Codominant Sprouts per Stump	
		Plateau	Ridge and Valley	Plateau	Ridge and Valley	Plateau	Ridge and Valley
Spp. Group	Trmt	n	n	mean±SE	mean±SE	mean±SE	mean±SE
Red oak group	CC	72	90	5.5 ± 0.55 AB *	3.6 ± 0.22	3.6 ± 0.38 A *	2.3 ± 0.19 A
	LT	66	77	5.9 ± 0.99 A *	3.3 ± 0.39	4.0 ± 1.09 A *	2.4 ± 0.37 AB
	SW	89	134	4.2 ± 0.69 B	3.0 ± 0.26	2.4 ± 0.41 B	1.6 ± 0.15 B
Chestnut oak	CC	44	107	3.8 ± 0.49	4.8 ± 0.26 *	2.6 ± 0.35	2.6 ± 0.17
	LT	29	87	3.9 ± 0.77	4.4 ± 0.29	2.8 ± 0.85	2.4 ± 0.16
	SW	28	116	4.0 ± 2.07	4.3 ± 0.35	1.7 ± 0.33	2.3 ± 0.25
Red maple	CC	264	73	6.2 ± 0.36 A	6.6 ± 0.60	3.8 ± 0.27 A	3.7 ± 0.41 A
	LT	162	66	5.9 ± 0.40 AB	6.8 ± 0.53	3.8 ± 0.37 A	3.4 ± 0.34 A
	SW	268	48	4.9 ± 0.32 B	6.2 ± 0.67	2.6 ± 0.18 B	2.7 ± 0.26 B
White oak/ Hickory	CC	24	45	-	3.2 ± 0.37	-	2.4 ± 0.27
	LT	16	85	-	2.8 ± 0.44	-	2.0 ± 0.32
	SW	18	54	3.0	3.1 ± 0.41	-	1.8 ± 0.31
Mixed Mesic	CC	190	15	4.3 ± 0.33	4.7 ± 0.28	2.8 ± 0.58	3.4 ± 0.24 A
	LT	222	29	3.9 ± 0.27	3.7 ± 0.42	2.9 ± 0.29	2.7 ± 0.29 AB
	SW	250	27	4.1 ± 0.35	3.1 ± 0.34	2.6 ± 0.50 *	1.6 ± 0.15 B
Midstory	CC	264	223	4.5 ± 0.35	4.3 ± 0.88 A	2.8 ± 0.22	4.5 ± 0.50 A *
	LT	433	160	3.6 ± 0.34	4.3 ± 1.08 AB	2.3 ± 0.25	3.0 ± 0.53 AB
	SW	233	226	4.1 ± 0.23	3.0 ± 1.00 B	2.5 ± 0.15	1.5 ± 0.50 B

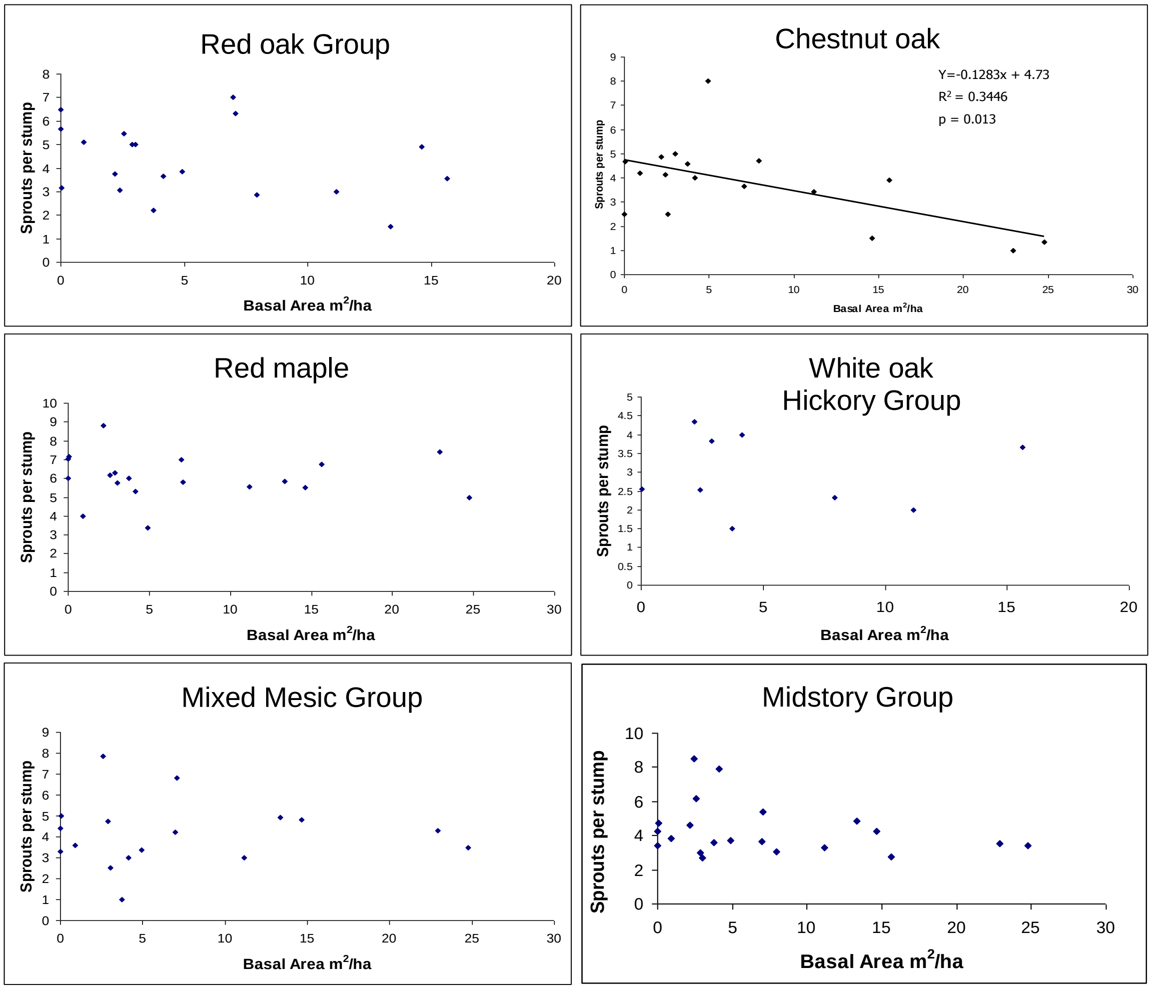


Figure 6.5. Regression analysis of the number of all sprouts per stump by the residual basal area (m^2/ha) for each species group 9-11 years after harvest. Trend lines, equations, and R^2 values are displayed for significant (α<0.05) relationships.

Sprouting in the chestnut oak group was greater than in the other oak groups. However, it too dropped in the partial harvesting treatments. In the RV, sprouting dropped from the CC (78%) and LT (73%), to the SW in which only 33% of stumps sprouted; but on the AP it dropped from 50% in the CC to 35 and 18% in the LT and SW respectively.

In contrast to the oak groups, stump sprouting in the red maple and mixed mesic groups did not consistently decrease in the partial harvesting systems (Table 6.3.). For example in the RV, the percent of stumps of red maple that sprouted was higher in the LT (70%) than in the CC (49%). Likewise, in the mixed mesic group on the AP, sprouting in the SW (61%) was greatest while in the RV the LT (30%) was greatest.

To better estimate the potential contribution of stump sprouts to future stand composition, a separate analysis was conducted on stumps that produced competitive stump sprouts (CSS). This analysis was based on the percent of stumps that produced a dominant or codominant sprout. Dominant and codominant sprouts were those sprouts which were in the uppermost strata or above within the regeneration canopy.

In the analysis of the proportion of stumps that produced competitive sprouts, the red oak species group showed much higher rates of sprouting in the RV than on the AP (Fig 6.3.). In the RV CC 57% of stumps produced competitive stump sprouts while only 30% of those in the CC on the AP had competitive sprouts. There were differences in competitive sprouting among the treatments within provinces. Fewer stumps sprouted in the LT and SW compared to the CC. The proportion of stumps with competitive sprouts on the AP ranged from 30% in the CC, to 16% in the LT and 14% in the SW. The impact of these treatments was even more pronounced in the RV where the proportion of competitive sprouts declined from 57% in the CC to 20% in the LT and 27% in the SW. Regression analysis showed residual basal area to be negatively correlated with the proportion of stumps with competitive sprouts (Fig. 6.4). The AP averaged more sprouts per stump than the RV for the CC and LT (Table 6.4). The SW had the least number of competitive sprouts per stump. However no relationship was found between residual basal area and the number of sprouts per stump in the red oak group using regression analysis (Fig. 6.5).

Chestnut oak in the RV had the highest proportion of stumps with competitive sprouts with 77% in the CC. In the RV 72% of the chestnut oak stumps had competitive sprouts in the LT, but only 35% in the SW (Fig 6.3). The proportion of stumps with competitive sprouts on the AP was lower overall, and it decreased from the CC with around 44%, to only 15% in the LT, and 12% in the SW. Regression analysis showed a negative correlation between residual basal area and the percent of those chestnut oak stumps with competitive sprouts (Fig. 6.4). There were more competitive sprouts per stump in the RV than in the AP (Table 6.4). Regression analysis revealed that as residual basal area increased the number of sprouts per stump of chestnut oak decreased (Fig 6.5.).

The white oak/hickory group had no stumps with competitive sprouts on the AP and less than 30% in the RV (Fig. 6.3). The proportions of stumps with competitive sprouts were fewer in the LT (19%) and the SW (12%) compared to the CC (28%) in the RV. Regression analysis of basal area and percent of stumps with competitive sprouts was not significant (Fig. 6.4). There was no effect of residual basal area on the number of sprouts per stump (Table 6.4, Fig. 6.5).

Red maple displayed the highest overall mean percents, of stump with competitive sprouts, across all province and treatment combinations (Fig 6.3). All treatments except the RV SW had competitive stump sprout means above 40% with two treatments, the RV LT and the AP CC, above 60%. Red maple also showed a negative correlation between residual basal area and percent of stumps with competitive sprouts (Fig 6.4.). The average number of competitive sprouts per stump decreased from the CC and LT to the SW on both provinces (Table 6.4). However no relationship was found between residual basal area and the number of sprouts per stump using regression analysis (Fig. 6.5).

The results in the mixed mesic species group were more variable (Fig 6.3 & 6.4). There was no consistent trend in the percent of stumps that produced competitive sprouts among treatment, or residual basal area. However, the shelterwood on the AP had the highest with 55% of stumps producing competitive sprouts, which was unlike any other species group. The SW in the RV averaged fewer competitive sprouts per stump,1.6, than the RV CC, 3.4, and the AP, SW, 2.6 (Table 6.4). However no relationship was found between residual basal area and the number of sprouts per stump using regression analysis (Fig. 6.5).

Sprouting in the midstory group was greater in the RV, where 34% of the stumps in the CC produced competitive sprouts (Fig 6.3). The highest rate on the AP was in the CC, with only 14% of stumps producing competitive sprouts. In the RV sprouting decreased in the alternative treatments to 18% in the LT, and to 12% of stumps, in the SW, with competitive sprouts. The regression analysis of residual basal area and the percent of stumps that produced competitive sprouts displayed no significant trends (Fig. 6.4). The SW had fewer competitive sprouts per stump, 1.5, than in the CC, 4.5, in the RV which also had more than the CC on the AP, 2.8 (Table 6.4). However no relationship was found between residual basal area and the number of sprouts per stump using regression analysis (Fig. 6.5).

5. Discussion

The results of this study suggest that on fair to good quality sites in the southern Appalachians, silvicultural systems which retain residual trees can significantly reduce the number of harvested oak stumps which sprout. This must be taken into consideration when deciding which silvicultural systems are to be used in this region. Alternative systems which retain residuals will likely cause a shift in species composition of the future stand, especially if they negatively affect the most competitive form of regeneration for that species. Stump sprouts were the most important form of regeneration for oaks on these sites because no advance regeneration was present prior to harvest (Lorber 2002). Stump sprouts must be strongly considered in management strategies for the southern Appalachians.

Red oak group stump sprouting was greatest in the CC on both provinces. The RV 9-11 year sprouting survival rates were similar to what others have predicted for first year stump sprout survival (Weigle and Johnson 1998). The intercept for the regression of sprouting versus residual basal area, which indicates sprouting following a complete CC, was 55. This is close to the one year post harvest survival prediction for stump sprouts, indicating either higher initial rates of sprouting or negligible mortality for stump sprouts

(Fig. 6.3). A large drop was exhibited in both provinces in the presence of residual basal area. Sprouting of the oaks decreased around 2% for each 1 m^2/ha increase in residual basal area (Fig. 6.4). The number of sprouts per clump was similar to that reported by Johnson (1975). In both physiographic provinces there were more competitive sprouts per stump in the CC than in the SW. This suggests that residuals reduce both sprouting frequency and vigor.

Although chestnut oak sprouted more frequently than red oak, residual basal area had a similar impact on the proportion of stumps that sprouted. Sprouting also declined around 2% for each 1 m^2/ha increase in residual basal area. Again the trend was similar on the AP with a large decline from the CC to the alternatives. Sprouting in chestnut oak was the most prolific among the oaks, which has also been observed in several other studies (Cook et al. 1998, Weigel and Johnson 1998, Campbell 1965). A drop of this magnitude for both provinces could have serious impacts on chestnut oak's ability to perpetuate itself in these stands. The low rates of sprouting on the AP in general and especially in the LT and SW indicate that stump sprouting may not be a reliable source of regeneration for chestnut oak on similar sites in this region. This is surprising due to the normally high rates of sprouting attributed to this species (Cook et al. 1998, Weigel and Johnson 1998). In the CC, chestnut oak had an average of 4.5 sprouts per stump with 2-3 of these in competitive positions. These data seem consistent with other observations (Cook et al. 1998). However as residual basal area increases, these numbers decline, which could reflect a loss of stump vigor and could decrease the number of stems of this species in subsequent stands.

The white oak/hickory group sprouted very poorly in all of the treatments. In the RV CC it performed similarly, around 30% sprouting, to what Weigel and Johnson (1998) predicted for similar conditions. This suggests that sprouting is not a reliable source of regeneration for these species under similar conditions. Further regression analysis of just the RV sites, although not significant, did show that sprouting also declined by around 2% for every 1m^2/ha of residual basal area, similar to the other oak groups.

Red maple showed the overall highest average rates of sprouting. The intercept of the regression indicated 65% of stumps would sprout in a complete clearcut. Unlike the oaks, red maple retained a higher sprouting ability as residual basal area increased. The greatest sprouting rate of red maple was in the LT in the RV. This treatment saw a large reduction in red oak group sprouting. Though red maple's sprouting ability is reduced by increased residual basal area, its sprouting remains higher than that of more desirable oak species. Also it appears stump sprouts are proving to be an important form of competitive regeneration for red maple as it becomes established in these stands post-harvest.

The mixed mesic group did not seem to follow any trends among the treatments. Sprouting in the mixed mesic group was generally higher on the AP than in the RV. The SW in the RV had fewer sprouts per stump than all of the treatments, which were similar. This may cause a problem where oak sprouting is reduced, in the presence of residual basal area, but mixed mesic species are unaffected.

The midstory species performed much better in the CC in the RV than in any other treatment province combination. This combination had the highest percent and the most competitive sprouts per stump for the species group. It also had one of the highest numbers of competitive sprouts per stump over all species groups. Trends showed sprouting success for these species to decline with increased residual basal area in the RV. This could be beneficial in the shelterwood for recruiting advance oak regeneration under partial canopy conditions.

A cause of the reduced spouting for the oak species in stands where partial harvesting leaves residual trees in the stand could lie in oak's ability to root graft (Lyford, 1980). Other trees have been shown to affect cut stumps through root grafting (Loehle and Jones 1990). The decrease in sprouting of the oak in the partial harvests may also be attributed to lower light levels. However, Lorber (2002) revealed that the clearcut had higher light levels than the leave-tree and shelterwood, but the leave-tree and shelterwood had similar light levels. The light level differences could explain the stump sprouting differences between the CC and the alternative treatments, but not the difference seen between the alternatives. A more probable cause is root grafts. Root grafts may reduce sprouting and vigor of cut stumps because of competition for water and nutrients, and chemical communication through these grafts (Bormann 1966, Kozlowski and Cooley 1990, Loehle and Jones 1990). Uncut trees can take the nutrients and carbohydrates stored in the root systems of trees which have been harvested via root grafts creating a parasitic relationship through the grafts (Bormann 1966, Loehle and Jones 1990).

Stump sprouts are produced from dormant buds near the base of a cut stump (Johnson et al. 2002). Dormant buds are buds that developed in leaf axils and therefore are still connected to the tree's pith (Kozlowski and Pallardy, 1997). These buds are kept dormant through a hormonal feedback mechanism from dominant apical meristems. That results in low concentrations of Auxin (IAA), a growth promoter, and high levels of Abscisic Acid (ABA), a growth inhibitor. When the dominant meristem is removed these hormonal feedbacks are removed and the dormant buds at the base of the tree become active, divide and expand to form stump sprouts. Apical meristems of residual trees which are connected to the cut stumps through root grafts could maintain hormonal control and decrease the vigor or inhibit the formation of stump sprouts in stands that have undergone partial harvesting treatments, as was demonstrated in this research.

All of these impacts must be considered when implementing alternative silvicultural treatments. The treatments all serve specific sets of goals; but by relying on regeneration sources from more traditional silvicultural methods which do not leave residuals in the stand, managers may in fact not have an accurate representation of the regeneration potential for target species. It has been shown that the most competitive form of regeneration for oaks on fair quality sites in the southern Appalachians is stump sprouting. If the density and vigor of sprouts are reduced by partial harvesting systems, species shifts can be expected under these systems. This study presented strong evidence all oak species, regardless of initial sprouting rates, exhibit around a 2% reduction in sprouting as residual basal area is increased by $1m^2$/ha. These same effects are not seen in oak's competition on these sites. Maple's sprouting peaked in a partial harvest treatment where red oak group's sprouting saw the largest reduction. The mixed mesic species also showed no effect from residual basal area and peaked in a treatment which had the lowest sprouting of all oak species. This a serious concern on sites where oak is being replaced by other more mesic species such as yellow-poplar, which do not show similar effects or nearly as strong of an effect from these partial harvesting systems. This suggests alternative silvicultural systems, such as a LT and SW, are not fostering favorable conditions to regenerate oak because stump sprouts, the traditional source of regeneration in this region, are negatively affected by the residual trees. Managers must be aware of these potential problems before implementing alternative silvicultural systems in stands in the southern Appalachians where other forms of oak regenerations are limited or not present.

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7. Discussion

These two studies indicate that on fair sites in the southern Appalachians alternative silvicultural practices have an effect on regeneration 9-11 years after harvest. Residual trees when left in stands at variable distributions and densities impact the regeneration in a number of ways. The alternative silvicultural systems reduced height growth, altered species composition and competitive abilities, and affected stump sprouting and vigor compared to clearcutting. Also the residuals themselves are affected exhibiting increased numbers of defects compared to the control, which in some cases devalues the most valuable component of the stand (Appendix 2). These are all serious impacts that must be considered when planning forest management activities in this region. Now that management objectives are more diverse and complex, sound responsible decisions based on adaptive management must consider the impacts of reserve trees on forms of regeneration, the regeneration environment, and residual trees.

These results show that stump sprouting is the dominate form of oak regeneration across all of the treatments. Most sites in this region with site qualities, within the range investigated, do not have advance oak regeneration present in the understory. It was indicated in the results of the herbicide treatment (Table 5.4) that midstory competition can be reduced, but oak advance regeneration did not increase under the subsequent conditions as found in other studies (Loftis 1985, Lorimer et al. 1994).

The clearcut results demonstrated the highest rates of stump sprouting for all of the oak species. Sprouts proved to be the most numerous, reliable, and competitive form of oak regeneration in this treatment. On both provinces maple sprouting was much more numerous than seedling origin regeneration, but sprouts did not prove to be taller. This increase in importance could perhaps be somewhat reduced or controlled through a pre-harvest cleaning treatment, as the herbicide treatment results indicated. The black cherry-yellow-poplar group also replaced some of the oak and increased importance in the full light conditions created on these fair sites by both more competitive sprout origin regeneration, and more numerous seedlings. It appears as though these data reflect the predictions made by Cook et al. (1996), for post-clearcut oak regeneration to retain over a quarter but less than half of future canopy composition in stands on sites of fair quality.

The commercial harvest reduced height growth compared not only to the clearcut but also the leave-tree, which had a similar mean residual basal area. This indicates what previous work has shown reflecting the reduced growth and yield which results from such treatments (Trimble 1971, Fajvan et al. 1998). There were reductions in height growth of both the oak and maple species compared to the clearcut. However maple densities were also reduced, especially the stump sprouts. This may be attributed to the number of maple residual left in this harvest, as larger more desirable timber species were harvested (Appendix 3). Miscellaneous species seemed to respond well to the commercial harvest and did not show adverse growth or density effects. The black cherry-yellow-poplar group seedlings responded very well to this treatment as well, with increased density and competitive mean height. The problem with projecting future stand composition from the regeneration data is that there were similar numbers of residuals left in these stands compared to the shelterwood (Appendix 4). The implications of not removing these residual and forming a two-age or uneven-aged stands means that the species composition of these residual will play a large part in the species composition of the future stand. Therefore it can be certain that a likely species shift, from the original overstory, will occur in this treatment not only because of regeneration differences but also from those residual of less desirable species left in the overstory.

The leave-tree had lower oak sprouting levels than the clearcut, but had very similar values in terms of average regeneration height and the average density of competitive stems among the tallest regeneration. However when all dominant and codominant oak stems are examined, the leave-tree had on average fewer and shorter oak regeneration stems than the clearcut (Appendix 5). This reflects the influence of these residual on growth and species composition as well as stump sprouting after harvest. At this point it is not clear if these effects will actually translate into overstory differences from the clearcut when these stands mature. Results do indicate that there will be shifts in species composition between the pre-harvest and post-harvest canopies similar to those in the clearcut, but these are only predictions based on current stocking levels, which can shift drastically in the next thirty years as the stand continues through the high stress and mortality conditions created by competition in the stem exclusion phase.

The shelterwood results indicated that oak advance regeneration can be fostered with moderate canopy disturbance. However this comes at a cost of oak stump sprouts, which in the other treatments have proven to be the most reliable, competitive, and numerous form of oak regeneration. Also, without the reduction of the midstory through a disturbance or herbicide, other tolerant species such as maple also form similar numbers of equally, or more competitive stems in the understory (Figure 5.5). These tolerant stems may be established enough that after the removal of the overstory they may out compete any stump sprouting contributed by those residuals which are removed. These residuals may also have reduced sprouting abilities because of increased age and diameter. It appears as though the cost of building advance oak regeneration in the shelterwood comes in the form of reduced numbers of competitive oak stump sprouts. Without any disturbance to favor the oak advance regeneration formed under the shelterwood, after the final harvest, oak's competitive ability will be no more favored and could possibly be less so due to the lack of stump sprouts as compared to the clearcut and leave-tree. However, dispersed skidding has been used to top kill regeneration which may favor oak advance regeneration because of large established root systems which can support good form competitive shoots (Larsen and Johnson 1998).

The group selection reduced oak and maple growth, however maple density proved to be the highest in this treatment. There were fewer intolerant black cherry-yellow-poplar stems in this treatment than any of the others, but those present were of seedling origin and the tallest of the black cherry-yellow-poplar regeneration. This indicates that in uneven-aged management systems in the southern Appalachians tolerant regeneration is favored, but the intolerant regeneration that survives in the cut can be successful in the subsequent light conditions as was observed by Smith (1981). These results do also differ from the clearcut displaying overall regeneration height growth reductions. Oak composition in the subsequent canopy may be similar to that of the clearcut, but it appears more tolerant maple species will increase at the expense of the reduction of the intolerant black cherry-yellow-poplar species relative to the other treatments.

All of these impacts must be considered when implementing alternative silvicultural treatments. The treatments all serve specific sets of goals; but by relying on regeneration sources from more traditional silvicultural methods which do not leave residual in the stand, managers may in fact not have an accurate representation of the regeneration potential for target species. Variable retention harvests on fair sites in the southern Appalachians do not seem to have a large impact on the densities of species in the regeneration 9-11 years post harvest. However height growth was impacted among the treatments in every species group. At this stage it is not clear which trees will comprise the canopy of the next stand; but by eliminating those species not normally capable of reaching canopy positions and only looking at the tallest 365 stems/ha, at this point it appears that stump sprouts still hold a competitive advantage for all species in at least two if not more of the treatments. It was also shown oak's most numerous and competitive form of regeneration on fair quality sites in the southern Appalachians is stump sprouting. It was also shown the density and vigor of sprouts is reduced in partial harvesting systems. These studies indicate species shifts are apparent in the 9-11 year regeneration and may be expected in the next mature stands under these systems. It also does appear as though oak will lose importance in the next stand, but again it is hard to predict which species will fall behind as competition becomes more intense and mortality increases as the stem exclusion phase continues into the future. Managers must be aware of these potential implications on species, however, before implementing these alternative systems.

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Appendices

1. Percent of stumps that sprouted dominant or codominant sproutes 9-11 years after harvest by each species.

Percent of Stumps with Dominant or Codominant Sprouts												
Province	Plateau						Ridge and Valley					
Treatment	CC		LT		SW		CC		LT		SW	
Species	n	pct	n	pct	n	pct	n	pct	n	pct	n	pct
A. pennsylvanicum	13	0.0	152	23.7	18	0.0						
A. rubra	234	60.7	138	43.5	224	42.9	63	41.3	60	66.7	45	26.7
A. Sacharum	11	9.1	88	11.4	9	11.1						
A. arboria	37	0.0	22	4.5	34	8.8			3	33.3	1	0.0
B. alleghaniensis					2	0.0						
B. lenta	13	0.0	13	0.0	37	16.2	6	0.0	5	60.0	1	0.0
C. dentata	3	0.0			6	50.0	1	0.0	5	0.0	5	0.0
C. glabra	1	0.0	4	0.0	2	0.0	1	0.0	7	57.1	6	0.0
C. tomentosa	2	0.0	1	0.0			13	0.0	23	8.7	25	0.0
C. florida	12	0.0	3	0.0	5	0.0	16	6.3	18	0.0	17	0.0
F. grandifolia	67	9.0	115	1.7	20	0.0						
F.americana			1	100.0			5	0.0	4	0.0		
F. pennsylvanicum									2	100.0		
H. virginiana	1	0.0	5	20.0	7	14.3	1	0.0				
I. montana	1	0.0										
L. tulipifera	5	20.0	23	21.7	18	33.3	8	12.5	20	30.0	24	8.3
M accuminata	43	62.8	10	20.0	17	41.2	1	100.0			2	0.0
M. fraseri	66	36.4	36	25.0	126	61.9						
N. sylvatica	10	0.0	8	0.0	15	0.0	60	5.0	52	1.9	79	0.0
O. virginiana	1	0.0	1	100.0								
O. arborium	26	42.3	28	21.4	30	40.0	103	58.3	60	33.3	92	28.3
P. avium							1	0.0				
P. pennsylvanicum	2	0.0	1	0.0								
P. serotina	47	42.6	18	61.1	43	58.1			2	0.0		
Q. alba	21	0.0	11	0.0	15	0.0	25	40.0	49	18.4	19	31.6
Q. cocciniea			2	0.0			49	53.1	45	17.8	86	33.7
Q. prinus	39	43.6	26	15.4	26	11.5	98	76.5	82	72.0	107	34.6
Q. rubra	45	37.8	57	17.5	76	13.2	1	100.0			6	16.7
Q. velutina	15	6.7	2	0.0	3	33.3	34	61.8	23	26.1	32	12.5
R. pseudoacadia	3	0.0	9	0.0	9	0.0	6	33.3	2	50.0	5	0.0
S. albidum							4	25.0	2	0.0	11	0.0
T. americana			22	4.5								

2. Bole defects in the lower 6 m, 9-11 years after harvest for all species.
Letters represent differences from the other treatments and the control. NS – no significant effects.

		Large Branches (> 3 cm)	Small Branches (< 3 cm)	Basal Sprouts
Treatment	n	Mean ± SE	Mean ± SE	Mean ± SE
CC	63	1.82±.35 C	4.1± 0.7 B	0.46± .13 A
CH	284	2.23±.23 C	3.3± 0.5 A	0.49± .07 B
LT	209	1.50±.24 C	3.5± 0.5 A	NS
SW	286	1.58±.22 C	2.7± 0.5 A	0.21± .07 A
GP	474	1.15±.21 B	3.5± 0.5 A	0.21± .06 A
CT	988	0.85±.19 A	2.6± 0.5 A	NS

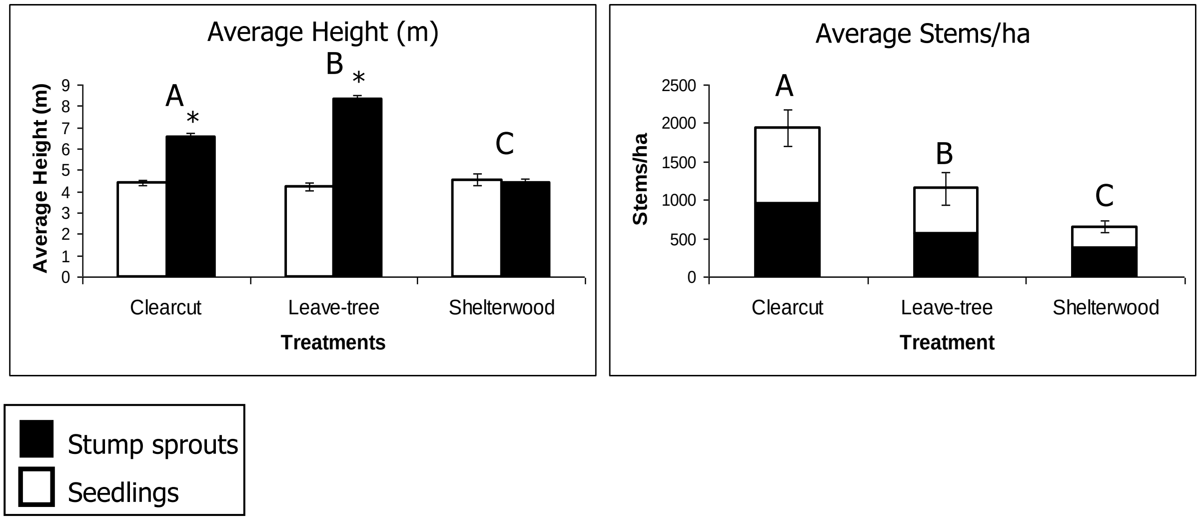
3. 9-11 year post harvest overstory composition (stems/ha) by species group and treatment.

9-11 Year Post Harvest Residuals (stems/ha)

Species Group	Treatment	Mean ± SE
Oak	CH	37.1 ± 11.4
	LT	34.7 ± 14.0
	SW	99.4 ± 21.9
	GP	90.2 ± 15.2
	HB	273.1 ± 82.0
	CT	219.2 ± 81.4
Maple	CC	24.6 ± 15.2
	CH	99.6 ± 52.2
	LT	54.4 ± 31.5
	SW	54.4 ± 23.0
	GP	165.0 ± 39.5
	HB	202.7 ± 87.3
	CT	251.9 ± 56.3
Black cherry-yellow-poplar	CH	20.8 ± 4.3
	LT	18.3 ± 9.3
	SW	25.1 ± 13.9
	GP	47.8 ± 24.7
	HB	52.1 ± 18.3
	CT	79.6 ± 19.1
Micellaneous	CC	34.7 ± 5.8
	CH	84.5 ± 32.6
	LT	49.2 ± 10.7
	SW	60.8 ± 29.6
	GP	54.0 ± 14.8
	HB	113.9 ± 36.7
	CT	113.3 ± 31.6
Midstory	CC	40.5 ± 20.2
	CH	108.6 ± 37.8
	SW	93.8 ± 32.5
	GP	86.9 ± 20.9
	LT	64.7 ± 23.1
	HB	145.7 ± 30.5
	CT	260.6 ± 45.5

4. Overstory density (stems/ha) by treatment by treatment 9-11 years after harvest.

Treatment	Mean ± SE
CC	52.0 ± 26.6
CH	271.7 ± 92.5
LT	167.6 ± 65.9
SW	277.4 ± 65.3
GP	393.0 ± 60.1
HB	716.7 ± 67.6
CT	820.8 ± 100.6



5. Oak dominant and codominant regeneration 9-11 years post harvest.
Letters represent significant differences among treatments and asterisks represent differences between sprout and seedling origin regeneration ($\alpha < 0.05$).