# Effects of Understory Vegetation Manipulation on Hardwood Regeneration Recruitment and Growth in Southern Appalachian Forests

by

Jesse Warren Thompson

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APPROVED:

David Wm. Smith, Chair

Shepard M. Zedaker

James E. Johnson

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(ABSTRACT)

The successful regeneration of mature oak (*Quercus* spp.) forests is thought to be dependent on the presence of oak advance regeneration. However, the advance regeneration must be of sufficient size and density for oak to be competitive and become a dominant species after harvest. The presence of a dense midstory canopy of shade tolerant species has been implicated with the poor development of oak advance regeneration.

Understory Vegetation Control was conducted in 1994 in average quality ($SI_{50}$ 17.7 - 21.9 m for upland oak) southern Appalachian forest stands to determine the effects on oak (*Quercus* spp.) and maple (*Acer* spp.) advance seedling abundance, growth, and development. Three study sites were located in southwest Virginia, and the following two treatments were implemented at each site: Understory Vegetation Control (UVC) and Control. Permanent sampling plots and individual seedlings were located to quantify the density, recruitment, and growth of advance regeneration.

Competing vegetation was significantly reduced after one year by the UVC treatment, where the mean relative change in the sum of the heights of competing stems between

1 and 5 m in height was -15.9 percent for the UVC plots vs. 22.8 percent for the Control plots. Neither oak seedling recruitment nor height growth was enhanced by the UVC treatment after one year.

Insufficient time has elapsed to allow for a growth response, or to determine if seedling recruitment will be enhanced by UVC. Several years may be required to determine if the UVC treatment can enhance the growth and competitive status of oak regeneration.

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## PREFACE

Biological diversity is becoming an increasingly important forest resource management issue. There is much concern both within the scientific community and the general population over the loss of biological diversity on an ecosystem level. Because of this concern and because traditional harvesting techniques can impact diversity, their effects on diversity have come under considerable scrutiny. In order to accurately predict how certain forest management practices will affect the biological diversity of an area, more research must be done. Long-term studies which monitor the development of forest communities following traditional regeneration methods, and/or other silvicultural practices, are likely the best way to achieve an understanding of the effects of these practices on biodiversity.

The study entitled "Impacts of Silviculture on Floral Diversity in Southern Appalachian Forests," hereafter termed "the diversity study," has been implemented for the purpose of creating a long-term ecological monitoring system that will quantify the effects of several silvicultural techniques on floral diversity. The study for which this justification is written, hereafter termed "the regeneration study," focuses on the Understory Vegetation Control (UVC) and Control treatments used in the diversity study. The UVC treatment entailed the reduction, via an individual stem (basally applied) herbicide treatment, of stems between 1 and 5 meters in height not listed as one of the top 14 species in the preferred species list (Appendix A). The Control treatment received no manipulation. While the diversity issue is not the focus of the regeneration study, the data obtained should provide some important information with regard to the regeneration of the highly diverse Appalachian hardwood forest region.

# INTRODUCTION and JUSTIFICATION

Forestland covers approximately 60 percent of the land area in Virginia, of which approximately 6.2 million hectares are classified as commercial timberland (Frame 1996). The wood products industry contributes almost $9.8 billion in value added annually and employs approximately 228,000 people both directly and indirectly (Frame 1996). While forestland, across all types, contributes much to Virginia's economy, upland hardwood forest types alone account for a significant portion of the total timberland area and forest products.

## Importance of Oak Forest Types

Upland forest types with an oak component encompass an area of 4.6 million hectares in Virginia, equalling approximately 73 percent of the total timberland area (Johnson 1992). These forests account for approximately 92, 41 and 75 percent of the non-industrial private forest (NIPF), National forest, and forest industry land bases, respectively, in Virginia (Johnson 1992). Oak species alone account for a significant percentage of annual merchantable growing stock removals: approximately 28 percent of all removals for all species (Johnson 1992). Given the significant contribution of upland hardwood forest types with an oak component to Virginia's annual timber supply, the successful regeneration of cutover hardwood forests is a matter of great concern to forest managers.

Virtually all upland hardwood stands not converted to pine plantations are regenerated naturally. For natural regeneration of cutover hardwood stands to be successful, resource managers must have a thorough understanding of the various sources of hardwood regeneration. Managers must also be familiar with the available methods used to increase the amount or quality of existing advance regeneration.

## Sources of Hardwood Regeneration

Sources of hardwood regeneration following harvest include new seedlings established at or after the time of harvest, older seedlings (advance regeneration) established prior to harvest, and sprouts originating from the stumps or roots of harvested trees (Beck 1980). New seedlings can generally be considered a viable source of regeneration for only very few species because they grow much too slowly to compete with other fast-growing stems, such as stump or root sprouts (Loftis 1990b). Pioneer species such as yellow-poplar (*Liriodendron tulipifera* L.), sweet birch (*Betula lenta* L.), and black locust (*Robinia pseudoacacia* L.) are among the few species that can successfully regenerate harvested stands as new seedlings (Kelty 1988). While stump sprouts exhibit a competitive growth rate, their contribution to regeneration diminishes as tree size and age of the parent stand increases (Ross *et al.* 1986). Therefore, stump sprouts alone cannot be relied upon for the successful regeneration of mature Appalachian hardwood stands (Sander 1972, Loftis 1983). Given the limitations of new seedlings and stump sprouts, it is likely that the only dependable source of abundant regeneration for many Appalachian hardwood species is advance regeneration (Kelty 1988). The dependence on advance regeneration for the successful regeneration of oak species is recognized by many researchers and has become a tenet of oak silviculture (Carvell and Tryon 1961, Sander 1971, Sander 1972, Loftis 1983, Kelty 1988, Loftis 1990b). Hereafter, newly germinated seedlings will be referred to as 'new seedlings' and the term 'seedling' is used synonymously with the term 'advance regeneration'.

Northern red oak (*Quercus rubra* L.) regeneration failures have occurred on a wide range of sites where it was a major component in the previous stand (Loftis 1990b). Recent evidence suggests that oaks will be replaced by other species on many sites, and many researchers recognize the problems associated with regenerating oak species (Johnson and Jacobs 1981, Lorimer 1989, Loftis 1990b, Marquis and Twery 1993, Sander and Graney 1993, Smith 1993, Lorimer *et* *al.* 1994). Problems with oak regeneration have been reported on sites of average and good quality in many parts of the eastern Unites States (Lorimer *et al.* 1994). The small size of oak advance regeneration relative to competing species has been suggested as a reason for the oak regeneration failures that have occurred (Lorimer *et al.* 1994).

The presence of a dense midstory canopy of tolerant and intermediate tolerant species has been implicated with the poor development of oak advance regeneration (Lorimer et al. 1994). Removal of such a midstory canopy has been shown, at least in some cases, to improve the size or growth rate of oak advance regeneration (Johnson and Jacobs 1981, Loftis 1988, Deen *et al.* 1993, Lockhart *et al.* 1993, Lorimer 1994). The reduction in fire frequency has also been implicated as a contributing factor in oak regeneration failures. Given that frequent fire would reduce understory and midstory vegetation, it is suggested that fire may enhance the development of oak advance regeneration by reducing the number of potential competitors and increasing the size of oaks relative to competing species (Swan 1970). The fire hypothesis lends additional credibility to the idea that the presence of a dense midstory may interfere with oak regeneration establishment and development.

An additional factor that substantially affects the development of oak advance regeneration, at least in some areas, is browsing by deer and other animals. The damage from browsing is so extensive in certain areas of the Appalachian hardwood region that very little advance regeneration is present.

**Previous Work on Oak Advance Regeneration**

Oak regeneration has received much attention in the literature in the past 20 years. While the majority of oak regeneration studies have focused on the use of various silvicultural techniques to enhance the amount and vigor of advance oak reproduction, few studies have dealt with determining or predicting the post-harvest performance of oak advance regeneration based on individual stem characteristics (Sander *et al.* 1976, Sander *et al.* 1984, Loftis 1990b). In a North Carolina study, Loftis (1990b) developed regression equations for the purpose of predicting the probability of northern red oak advance regeneration becoming dominant or codominant at age 20 using preharvest basal diameter and height and site index as independent variables. However, because the study by Loftis (1990b) was done on sites with site indices of 21 m and greater ($SI_{50}$ for oak), it would likely have limited applicability on sites of low to average quality ($SI_{50}$ 17 - 20 m for oak) where northern red oak is not present or is only a minor component.

Guidelines have been developed for evaluating the contribution of oak advance regeneration to future stand stocking (based on advance regeneration height and groundline diameter and topographic variables) on sites with site indices in the range of 15 to 23 m ($SI_{50}$ for black oak) in the Missouri Ozarks (Sander *et al.* 1976, Sander *et al.* 1984). Because the studies by Sander *et al.* were located in the central hardwood region, factors such as differing soil and climatic conditions, as well as differences in overstory and understory species composition may limit application of the results to the Appalachian hardwood region.

More research on individual stem characteristics of oaks and other desirable species is needed for average quality sites ($SI_{50}$ 20 m for oak) of the Appalachian hardwood forest region to provide forest managers with information that will ensure successful regeneration. A study that monitors the development of individual advance regeneration stems, as well as competing vegetation, would be useful in determining the minimum size of advance regeneration required to assure dominant or codominant canopy status in regenerated forest stands.

The objectives of the present study were to determine if understory vegetation manipulation via an herbicide treatment can: 1) improve the competitive status of existing advance regeneration and 2) recruit new regeneration by providing favorable forest floor conditions. Other objectives of this study were to 1) quantify the growth of individual seedlings, 2) quantify recruitment of new reproduction, and 3) quantify or identify the characteristics of seedlings that may ensure a dominant or codominant status in regenerated stands. Because the time available for this project was limited to two years, the results obtained are only preliminary; more time is required to adequately satisfy the main objectives of this study.

# LITERATURE REVIEW

Oak species are generally considered dependent on the presence of advance regeneration for successful regeneration (Carvell and Tryon 1961, Sander 1971, Sander 1972, Loftis 1983, Kelty 1988, Loftis 1990b). If oak species are to be perpetuated, silviculturists must have a knowledge of the many factors that can affect the establishment and growth of advance regeneration, which include 1) present and past forest structure and composition, 2) biotic and abiotic factors affecting seedling establishment and growth, and 3) silvicultural and cultural techniques that can provide the environmental conditions necessary for successful regeneration. The purpose of this section is to provide a review of the literature pertinent to the regeneration of Appalachian oak forests.

## Appalachian Oak Forests

Braun (1950) characterized the area extending from southern New England and the Hudson River Valley to northern Georgia as being included in the Oak-Chestnut Forest region. Since the chestnut blight, caused by the fungus *Cryphonectria parasitica* (Murr.) Barr., removed the American chestnut (*Castanea dentata* (Marsh.) Borkh.) from the overstory in this region, it is now termed the Appalachian hardwood region. The Appalachian hardwood region includes the Blue Ridge, Ridge and Valley, and Appalachian Plateaus physiographic provinces (Wenger 1984). The physiographic provinces of interest in the present study include the Ridge and Valley and the Appalachian Plateau, primarily because the soil types in these regions are of sedimentary origin, having limestone, sandstone, and shale parent materials. The Ridge and Valley province lies between the Appalachian Plateau, to the west, and the Blue Ridge, to the east, and is the primary focus of this section because two of the three study sites are located within this region. Because one study site is located on the fringe of the Appalachian Plateau and the Ridge and Valley province, some of the vegetation common to this area is included in this section as well.

In general, forest composition in the Ridge and Valley was at one time oak-chestnut on the ridges with mixed mesophytic communities in ravines and coves (Braun 1950). The mixed mesophytic communities still remain in the coves, but the American chestnut, once a dominant species in the region, was eliminated from the overstory by the chestnut blight in the early 1900's (Univ. of Ill. 1974). Currently, overstory species such as northern red oak and white oak (*Quercus alba* L.) are the main species in the region (Univ. of Ill. 1974). Chestnut oak (*Quercus prinus* L.) is another dominant overstory species, which forms a physiographic climax on drier slopes (Burns and Honkala 1990). Other common overstory species include scarlet oak (*Quercus coccinea* Muenchh.), black oak (*Quercus velutina* Lam.), and, to a lesser degree, red maple (*Acer rubrum* L.), sugar maple (*Acer saccharum* Marsh.), blackgum (*Nyssa sylvatica* Marsh.), and cucumbertree (*Magnolia acuminata* L.). Understory and mid-canopy tree species in the region include red maple, sassafras (*Sassafras albidum* (Nutt.) Nees), flowering dogwood (*Cornus florida* L.), and downy serviceberry (*Amelanchier arborea* (Michx. f.) Fern.). Common understory shrub species include such ericaceous species as blueberry (*Vaccinium* L. spp.) and mountain laurel (*Kalmia latifolia* L.).

## Biotic and Abiotic Factors Affecting Oak Regeneration

### Flowering and Fruiting

Flowering of many oak species occurs from late March to late May, which is about the same time as the leaves appear (Burns and Honkala 1990). The male flowers are borne in catkins and the female flowers are found either singly, in pairs, or in many flowered spikes, depending on the species. The pistillate flowers develop into acorns that, in general, mature in 1 year for species in the white oak group (*Leucobalanus*) and 2 years for species in the red oak group

(*Erythrobalanus*) (Harlow *et al.* 1979). Minimum seed-bearing age for many oak species is between 20 and 25 years, but maximum seed production often does not occur until age 50 (Burns and Honkala 1990). Even after the age of maximum seed production is reached, good seed crops occur only sporadically for most oak species. For example, good seed crops occur at intervals of 2 to 5 years for northern red oak and at intervals of 4 to 10 years for white oak (Burns and Honkala 1990). Variation in oak mast production has been associated with a number of factors including the number of pistillate flowers, the supply of pollen, weather, insects, as well as nutrition and genetics (Cecich 1992). Because of these factors acorn production varies greatly from year to year. For example, acorn yield for white oak has been reported to range from 0 to 499,135 seeds $ha^{-1}$ (Conner *et al.* 1976, Johnson 1975, Minkler 1965). Similarly, in 32- to 46-year-old pin oak (*Quercus palustris* Muenchh.) stands in southeastern Missouri, acorn production varied from 13,343 to 492,711 seeds $ha^{-1}$ over a 14 year period (McQuilkin and Musbach 1977).

Acorn dispersal for many oak species is accomplished in the fall by gravity, squirrels, mice, and blue jays (Burns, and Honkala 1990). Following dispersal, acorns not able to germinate in the fall require protection from freezing temperatures, desiccation, and predation over the winter in order to germinate the following spring (McQuilkin 1983). Korstian (1927) found that 2.5 cm of soil or 5 to 8 cm of litter can protect acorns from drying and low temperatures. A covering of litter can also protect acorns from those animals that locate acorns visually, thereby decreasing predation (McQuilkin 1983).

**Seedling Establishment and Development**

The number of seedlings becoming established may vary greatly from year to year, depending on the size of the previous years seed crop, predation, and climatic conditions. After a good seed year in West Virginia, Tryon and Carvell (1958) recorded an average of 6,330 stems $ha^{-1}$ of new oak germinants (all oak species). On plots that were considered to have 'good oak regeneration,' 9,397 stems $ha^{-1}$ of new oak germinants were found, and plots with 'poor oak regeneration' had a total of 3,264 stems $ha^{-1}$ of new oak germinants when all oak species were grouped together (Tryon and Carvell 1958). In another study in southern Missouri, an average of 667 new black oak seedlings $ha^{-1}$ were found following a good black oak acorn crop the previous fall (Sander 1979).

Subsequent to germination, white oak species immediately establish a taproot, while shoot development is delayed until the following spring (Burns and Honkala 1990).

Species in the red oak group also quickly establish a taproot upon germination, however, shoot development is not delayed and occurs in the spring with the initiation of taproot growth. The early and rapid development of a taproot may enable oak seedlings to survive considerable moisture stress later in the growing season (Burns and Honkala 1990).

Shoot height for oak seedlings one growing season after germination may range from 8 to 15 cm, with root length ranging from 18 to 25 cm, depending on the growing conditions (Watt 1979). Subsequent years growth may be relatively sluggish for oak seedlings, with growth averaging only a few centimeters per year (Sander 1979a). Oak seedlings typically require 30 percent full sunlight to reach maximum photosynthesis (Phares 1971). Light levels beneath a forest canopy are often much lower than 30 percent, however, and have been recorded to be only 10 percent of that found in the open, which is too low to allow seedlings to survive and grow (Burns and Honkala 1990).

True seedlings (stems with shoot systems the same age as their root system) seldom remain in the understory for more than a few years. Top dieback due to animal browse, insufficient light, or poor moisture conditions may occur, but the root system of the seedlings often remains alive (Burns and Honkala 1990). Many of the seedlings resprout, resulting in seedling sprouts that have a root system that is older than the shoot system (Sander 1971). Top dieback may occur several times, allowing seedling sprouts to persist in the understory for up to 90 years in species such as white oak (Burns and Honkala 1990). Liming and Johnson (1944) discovered that true seedlings were much less common than seedling sprouts. In their study of 4,800 small oaks in Missouri it was found that nearly 80 percent were seedling sprouts and that no true seedlings older than 7 years were found. The ability of oak seedlings to resprout following repeated top dieback allows for the build-up of advance regeneration under forest stands over time (Watt 1979, Burns and Honkala 1990).

**Problems Associated with Obtaining Adequate Regeneration**

Regenerating oaks in eastern forests on high quality sites ($SI_{50}$ 21 m and above for oak) has proven difficult and is often cited as a management problem (Loftis 1990a, b; Smith, H.C. 1992, Smith, D.Wm. 1992). While high quality sites often contain a substantial amount of oaks in the overstory, oak regeneration fails to compete with the faster-growing species following harvest regardless of the presence of oak advance regeneration (McGee and Hooper 1970, 1975; Beck 1970). Since new oak seedlings cannot compete with other faster-growing species, such as yellow-poplar, on high quality sites, the only types of regeneration with growth rates that can be considered competitive are stump sprouts and advance regeneration (Loftis 1990b). Because the contribution of stump sprouts to regeneration diminishes as stand diameter increases (Johnson 1977), and since very few small stems are found in the understory of high quality sites, the majority of dominant and codominant stems in regenerated stands must come from advance regeneration (Loftis 1990b). As was previously mentioned, the presence of advance regeneration does not necessarily secure successful oak regeneration. Advance regeneration must be of sufficient size and vigor to be able to compete with faster growing species (Sander 1984). It is likely that oak seedlings must have a position that is dominant among other understory seedlings to be competitive, especially on higher quality sites.

The development of a tolerant sub-canopy consisting of such species as red maple, sugar maple, and flowering dogwood is an additional factor that can have a negative impact on oak regeneration establishment and growth (Lorimer *et al.* 1994). The presence of such a sub-canopy can decrease the amount of light reaching the forest floor, as well as the amount of nutrients and water available for oak advance regeneration growth and development (Schlesinger 1993, Sander 1979b).

**Advance Regeneration Requirements**

Studies have shown that the size, number, and distribution of advance regeneration are the most important factors in determining the contribution of individual stems to future stands (Sander 1971, 1972; Sander and Clark 1971). In two studies by McGee and Hooper (1970, 1975) in the southern Appalachians, an average of 3,583 advance red oak stems $ha^{-1}$ were present. However, the advance reproduction did not compete well following clearcutting and dominant and codominant red oaks were found infrequently in the new stands. In another study in southwestern Wisconsin, 2,224 to 9,884 advance oak regeneration stems $ha^{-1}$ were found, but were considered inadequate because they were too small to compete with associated vegetation (Arend and Scholz 1969).

In a study in the Missouri Ozarks, Sander *et al.* (1976) determined that approximately 1,070 well-distributed stems per ha, 1.37 m tall or taller, were required to obtain a stand stocked at the C-level with dominant or codominant oaks when mean stand diameter is 7.6 cm. In contrast to the findings by Sander *et al.* (1976), Oliver (1978) found evidence suggesting that far fewer stems of northern red oak were needed than previously thought to obtain adequate stocking. In his study of mixed oak stands in New England it was determined that only 111 well-distributed and well-established stems $ha^{-1}$ were sufficient to secure eventual dominance of a stand (Oliver 1978). The results of the study by Sander *et al.* (1976) were later revised where the success of an individual advance regeneration stem was based on the standard of oak stump sprout height at age 5 (following clearcutting). Using this standard, a successful stem had to attain at least 80 percent of the height of oak stump sprouts at age 5, or a height of 2.7 m (Sander *et al.* 1984). Logistic regression analysis was then used to predict the probability for success of an individual stem based on the above success criterion, and initial and 5 year measurements (Sander *et al.* 1984). Aspect and slope position were also included in the prediction of success probabilities. The model by Sander *et al.* (1984) was validated using external datasets and was found to accurately predict "success" in 5 out of 6 stands. Loftis (1990b) has developed regression equations for predicting the post-harvest performance of advance regeneration based on individual stem characteristics for high quality sites in the southern Appalachians. In this study, Loftis used logistic regression methods to predict the probability of a stem becoming dominant or codominant by age 8 (P8), using preharvest basal diameter and site index; the criteria of being dominant or codominant at age 8 was considered met if the stem was determined free-to-grow and had attained 8/20 of the height at age 20 as indicated by site index curves. Using the P8 values, along with the assumption that the number of stems at age 20 is half that of the number of stems present at 8 years, 20 year dominance probabilities were calculated (Loftis 1990b). The resulting probabilities allow the silviculturist to determine the number of stems that will be dominant or codominant at age 20 based on site index, density, and basal diameter of individual stems. It should be mentioned, though, that because the model developed by Loftis (1990b) was not validated using external datasets, it is not known how well the model actually performs.

The above studies provide silviculturists with the ability to determine whether the existing advance reproduction in a given stand is sufficient to ensure adequate stocking of oak species in future stands following overstory removal. However, many times the number and size of the advance regeneration may be considered inadequate, in which case treatments must be prescribed to enhance or increase the amount of regeneration present.

## Silvicultural and Cultural Methods Used to Regenerate Oaks

The major silvicultural methods used to regenerate oak species include clearcutting, shelterwood, and group election. The use of prescribed fire and understory vegetation control (using herbicides) as cultural or site preparation methods has been suggested to aid in the regeneration of oak species. The above regeneration methods or silvicultural and cultural treatments are described in this section as they relate to the regeneration of oak species.

**Clearcutting**

Clearcutting can be successfully used to regenerate oaks if advance regeneration of sufficient size and vigor is present prior to harvest and/or sufficient potential for stump sprouts exist to compensate for a lack of advance regeneration (Sander 1971, Sander *et al.* 1976, Sander *et al.* 1984). The degree of success realized in using the clearcutting method of regeneration will likely vary according to site quality, however. A study in southwest Virginia showed that the contribution of oak advance regeneration to the future stands increased with decreasing site quality three years following clearcutting (Ross *et al.* 1986). In that study, oak species were in a better competitive position to gain dominance in the future stands relative to other species on the lower quality sites, but future dominance of oaks on the higher quality sites was questionable (Ross *et al.* 1986). A similar trend was shown in a study in the Virginia Piedmont where oak species were found to be in a better competitive position on lower quality sites than on higher quality sites two years following harvest (Kays *et al.* 1984). While the results of these two studies show promise for regenerating oaks on lower quality sites using the clearcutting method, they also show that the regeneration of oaks may not be successful on higher quality sites. This suggests that the use of other treatments, or treatment combinations, that enhance the size, number, and vigor of oak advance regeneration may be necessary to ensure that oaks are perpetuated in stands of higher quality.

**Shelterwood**

Various types of shelterwood treatments have been applied to Appalachian hardwood stands in an attempt to increase the regeneration potential of oak species. These treatments have had various degrees of success. In some cases oak regeneration was not enhanced and species composition following the treatment was essentially the same as that found following clearcutting (Loftis 1983). Other shelterwood treatments have also failed to increase or enhance oak advance regeneration (Sander and Clark 1971, Sander 1987). However, not all shelterwood treatments have resulted in the failure to improve oak regeneration. For example, shelterwood treatments imposed on good ($SI_{50}$ 21 m for black oak) and average sites ($SI_{50}$ 18 m for black oak) improved oak advance regeneration in the Missouri Ozarks

(Schlesinger *et al.* 1993). The results of the Missouri study showed that understory vegetation control coupled with overstory manipulation was necessary to improve oak advance regeneration on good sites, but an overstory treatment alone was sufficient on average sites to improve oak regeneration potential (Schlesinger *et al.* 1993). Shelterwood treatments accomplished from below, using herbicides, were found to effectively enhance the development of oak advance regeneration on good to high quality hardwood sites (Loftis 1990a). The treatments recommended as a result of this study involved reducing (from below using herbicides) the residual basal area to levels of 60%, 65%, and 70% for stands with site indices 21, 24 and 27 m ($SI_{50}$ for oak), respectively (Loftis 1990a). The rationale behind increasing residual basal area as site index increases is based on the premise that competition from fast-growing shade intolerant species such as yellow-poplar will be reduced. While the treatment recommended by Loftis (1990a) was shown to increase the competitiveness of established oak advance regeneration, it should be emphasized that there was no evidence that oak seedling establishment was enhanced.

While shelterwood treatments have been shown to increase the amount and/or vigor of oak advance regeneration in some cases, approximately 10 years or more may be required for the treatment to be successful (Loftis 1990a, Schlesinger 1993). In addition, understory reduction treatments may be necessary, especially on better sites, to reduce tolerant vegetation that would otherwise compete for light and nutrients (Schlesinger 1993, Sander 1979b). Such understory reduction treatments should improve the relative position of oaks to advance regeneration of other species, thereby increasing the likelihood of oak species being a dominant component in future stands. Understory treatments are described following the sections on Group-selection and Fire.

**Group Selection**

In contrast to the two previous regeneration methods mentioned, group selection is a form of uneven-aged silviculture. Group selection is a variant of single-tree selection, but is designed to regenerate shade intolerant and intermediate tolerant species because the size of canopy openings is greater than those created under single-tree selection. Under group selection, canopy gaps are generally restricted to a diameter of 1 to 2 times the height of the adjacent trees, which creates forest floor conditions different from clearcutting except near the center of the openings (Smith 1986).

The group selection method can be used to regenerate oak species; however, advance oak regeneration must be present prior to harvest to be successful (Sander 1980). Although there is little information on oak regeneration response to group selection treatments, a study in southern Michigan showed that group selection failed to successfully regenerate oak species in a stand with 65 percent of the original overstory basal area in oak species (Hill and Dickmann 1988). While no information regarding the presence of oak advance regeneration was provided in that particular study, it was mentioned that a sub-dominant stratum consisting of tolerant species such as sugar maple was present in the understory (Hill and Dickmann 1988). The results of this study suggest that a treatment reducing the tolerant subcanopy may be required in order to aid in the establishment and development of advance oak regeneration prior to harvest.

**Fire**

Many authors have suggested the use of prescribed fire to promote oak regeneration (Merritt 1979, Rouse 1985, and Loftis 1990a). One reason for the premise that fire can enhance oak regeneration is that oaks are known to be prolific sprouters; oaks are also less susceptible to root kill when exposed to fire than are other species, giving oaks a competitive advantage over their associates (Niering *et al.* 1970, Swan 1970). There is also some evidence that fire may provide more favorable conditions for oak seedling establishment due to the tendency of blue jays and squirrels to bury acorns in areas of thin litter, such as recently burned areas (Galford *et al.* 1988). While this information promotes the idea that the occurrence of fire will improve oak regeneration potential, it is still uncertain if prescribed fire can enhance oak regeneration in all cases. For example, a study involving a prescribed fire in the Central Appalachians showed that oak regeneration establishment was not enhanced and 66 percent of the overstory trees were damaged by the fire (Wendel and Smith 1986). However, because fire intensity was not well controlled across the treatment, little information regarding the potential effects of controlled burning on oak regeneration or main canopy stems can be garnered. Another study in the Southern Appalachians showed that a single fire had an adverse effect on oak survival, did not control competing vegetation, and did not enhance basal diameter growth of oak advance regeneration (Loftis 1990a). Little (1974) has suggested that repeated burns may be necessary to enhance oak advance regeneration, particularly on better sites. A study that used two burns in conjunction with a shelterwood treatment showed that oak regeneration was enhanced on good sites by the burning treatment, while on average sites the burns did not enhance oak regeneration

(Schlesinger *et al.* 1993). While this study shows some promise regarding the use of prescribed fire to promote oak regeneration, more information regarding the effects of fire on both the overstory and understory of Appalachian hardwood stands is needed before the use of fire in this region can be recommended. The inability to control fire intensity in steep terrain is of particular concern and may limit the use of fire due to the potential for damage to high-value overstory stems.

Another treatment that mimics prescribed fire, with regard to the type or size of vegetation that is controlled, is the reduction of understory and midstory vegetation using herbicides. This type of a treatment may enhance the development of oak advance regeneration by providing increased light to the forest floor via the reduction of the dense understory and midstory canopy that can prevent successful oak regeneration (Van Lear 1990, Loftis 1990a).

**Understory Herbicide Treatments**

The control of understory and midstory vegetation in combination with shelterwood treatments has been shown to improve the competitive status of oak advance regeneration in some studies (Loftis 1990a, Schlesinger 1993). While studies such as these have shown that understory control with overstory manipulation can enhance regeneration of oak species, few studies have reported the response of oak advance regeneration to understory-midstory vegetation reduction prior to overstory removal in upland hardwood stands (Loftis 1990a, Lorimer 1994). Several studies involving subcanopy removal have been done in bottomland hardwood stands, however (Janzen and Hodges 1984, Deen *et al.* 1993, Lockhart *et al.* 1993).

***Upland Hardwood Studies***

In a study in the Southern Appalachians, where all stems greater than 1.5 cm diameter at breast height (DBH) that were not a part of the main canopy were eliminated, oak regeneration basal diameter and survival were found not to be enhanced significantly over the control (no overstory or understory treatment) nine years after treatment (Loftis 1990a). This study did not provide information regarding the relative density of oak stems or their competitors, therefore no conclusions can be drawn regarding the treatment effect on that aspect of oak regeneration (Loftis 1990a). It should be mentioned that in the study by Loftis (1990a) the seedlings measured were established from seed prior to treatment initiation.

Removal of understory vegetation greater than 1.5 meters in height in mature oak stands in Wisconsin improved the survival and height growth of planted northern red oak seedlings. In addition, plots that received understory control were found to have 10 - 140 times as many natural oak seedlings after 5 years than undisturbed plots (Lorimer *et al.* 1994).

### *Bottomland Hardwood Studies*

Janzen and Hodges (1984) found that understory and midstory vegetation control in a high-quality ($SI_{50}$ 30.5 m for cherrybark oak (*Quercus falcata* var. *pagodaefolia* Ell.)) bottomland hardwood stand significantly increased oak seedling density three years after treatment, and oak seedling density decreased by about 30 percent in the plots that received no vegetation control. In addition, understory/midstory vegetation control significantly increased the mean height of cherrybark oak seedlings that germinated after treatments were established. Three years after treatment, cherrybark oak seedlings were 15.4 and 17.0 cm tall for the Inject and Inject/Spray treatments, respectively, compared to 9.6 cm for seedlings in control plots ($P < .05$) (Janzen and Hodges 1984). In another bottomland hardwood study by Deen *et al.* (1993) undesirable understory and midstory vegetation was eliminated with a glyphosate injection treatment and coupled with a coppice treatment on *Quercus* spp. (clip vs. no clip). Annual height increment was greater in the herbicide treatments than in the control, where annual height increment ranged from 3.4 to 16.6 cm for the inject-only treatment, 8.1 to 23.3 cm for the inject/clip treatment, and -10.9 to 5.1 cm for the control, over a seven year period prior to overstory removal. It should be noted that oak height growth response was delayed for 3 years for the inject-only treatment (Deen *et al.* 1993). However, two years after clearcutting, released seedlings were an average of 47 percent taller than seedlings in the control (Deen et al. 1993). In another bottomland hardwood study on cherrybark oak, the elimination of understory and midstory vegetation resulted in greater seedling survival and relative height growth four years after treatment (Lockhart *et al.* 1993).

While there have been several studies involving the effects of understory and midstory vegetation reduction on oak advance regeneration, information relating to the response of competing species to such treatments is lacking. The effectiveness of understory treatments cannot be adequately assessed where the response of competing species was not considered. This is especially true where tall advance regeneration is lacking, and the treatment is performed to enhance the growth or competitive stature of small oak advance regeneration. The present study provides information regarding the response of competing vegetation following the reduction of understory vegetation.

# PROCEDURES

The sites used in this study are located in the Ridge and Valley and Appalachian Plateau physiographic provinces of western and southwestern Virginia. The soils are derived from sandstone and shale parent materials.

## Study Site Selection

Study sites were selected such that the site quality, species composition, and physiography were representative of a large percentage of sites in the Appalachians. In addition, since the treatments used in the present study are a subset of the diversity study, the site boundaries needed to allow for the installation of seven, 2 ha square treatment plots, with the exception of the Fishburn site. Study sites were selected such that:

1) species composition was representative of typical mid-elevation (600-1050 m) southern Appalachian forests including such overstory species as scarlet oak, chestnut oak, white oak, and hickories (as indicated by U.S. Forest Service records);

2) site quality was in the range of 18 - 21 m at 50 years for upland oaks;

3) stand structure was not necessarily even-aged, but fairly uniform between and within sites;

4) the overstory was maturing or mature (between 50 and 150 years) and capable of providing an biddable harvest; 5) stand regeneration was a viable forest management option (optimal or near optimal rotation age had been reached);

6) slopes were moderate (between 10 and 40%) and aspects were predominantly southern; and

7) visual quality was maintained at a level acceptable to the U.S. Forest Service.

Suitable study sites were located in the Blacksburg and Clinch Ranger Districts of the Jefferson National Forest. An additional site was located at the Fishburn Tract in Blacksburg, Virginia. After site suitability was verified, treatment plot boundaries were located and permanent sampling plots were installed in each treatment plot at each of the three sites.

Permanent sampling plots for this study, with the exception of overstory subplots, were installed in May of 1994 and pretreatment data collected in June and July of 1994 for all three sites. Overstory subplots were installed and data collected in the summer of 1993 for the Blacksburg and Clinch sites and in the summer of 1995 for the Fishburn site. Treatment implementation was performed from late July to early August of 1994 for all three sites. Post-treatment data collection was performed in late summer of 1994; post-treatment data was not collected for overstory subplots.

## Study Site Descriptions

### Climate and Soils

The Blacksburg and Fishburn sites are located in Montgomery County, Virginia (Figure 1). Average annual temperature in Montgomery County is 10.6° C, with an average annual precipitation of 104 cm, and the average number of frost-free (above 0° C) days is 161 (National Oceanic and Atmospheric Administration 1993) (Table 1). Elevation ranges from approximately 671 to 716 m (2200 to 2350 ft) and 579 to 610 m (1900 to 2000 ft) for the Blacksburg and Fishburn sites, respectively (Table 1). The Clinch site is located in Scott County, Virginia. Climatic data from nearby Wise, Virginia (elevation 777 m) indicates the average annual temperature in the area to be 11.6° C, with an average annual precipitation of 117 cm; the average number of frost-free (above 0° C) days is 184 (National Oceanic and Atmospheric Administration 1993) (Table 1). Elevations for the Clinch site ranges from 1055 to 1097 m (3460 to 3600 ft).

Soils for the Blacksburg and Fishburn sites include the Berks and Weikert series which are classified as Loamy-skeletal, mixed, mesic Typic Dystrochrepts and Loamy

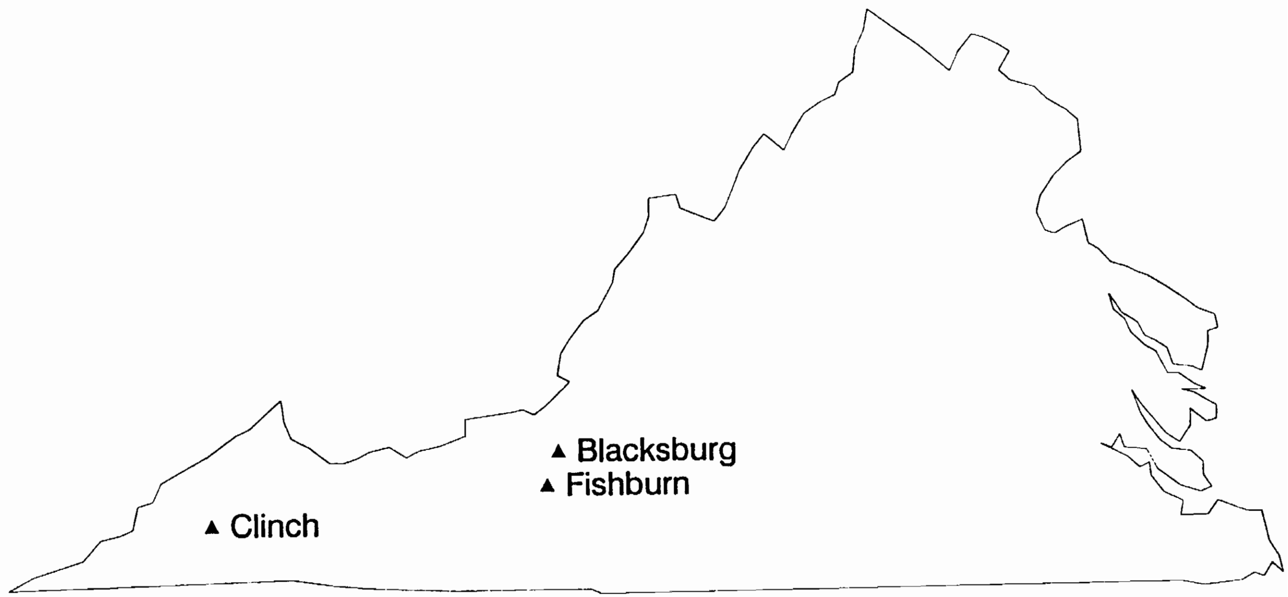


**Figure 1.** Virginia state map showing general location of study sites.

**Table 1.** Site characteristics for the Blacksburg, Clinch, and Fishburn study sites located in southwest Virginia.

| Site | Average Annual Temp. (°C) | Average Frost-Free Days | Slope (%) | Aspect (degrees) | Elevation (m) | FSQI[1] | | Site Index[2] (m) | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | UVC | CON | UVC | CON |
| Blacksburg | 10.6 | 161 | 2-35 | 050-327 | 671-716 | 10.5 (2.4) | 11.5 (4.1) | 18.5 (0.4) | 20.7 (1.2) |
| Clinch | 11.6 | 184 | 15-34 | 111-230 | 1055-1097 | 10.3 (1.3) | 8.8 (1.7) | 20.7 (2.1) | 23.1 (2.4) |
| Fishburn | 10.6 | 161 | 9-68 | 070-265 | 579-610 | 7.6 (1.7) | 8.3 (2.8) | 17.3 (3.2) | 18.0 (0.9) |
| Treatment means: | | | | | | 9.5[3] | 9.4 | 18.9 | 20.4 |
| P-value: | | | | | | .9420 | | .0926 | |

[1] Forest Site Quality Index (FSQI) values, for Understory Vegetation Control (UVC) and Control (CON) treatments, based on ordinal rankings assigned to slope, aspect and slope position values (Appendix D). Standard deviations are given in parentheses.

[2] Site Index values, for Understory Vegetation Control (UVC) and Control (CON) treatments, based on height at age 50 for upland oak (Olson 1959). Standard deviations are given in parentheses.

[3] Comparisons between treatments performed by ANOVA followed by Fisher's LSD.

skeletal, mixed, mesic Lithic Dystrochrepts, respectively (Creggar *et al.* 1985). The Clinch site soil is of the Muskingum series and is classified as Fine-loamy, mixed, mesic, Typic Dystrochrepts (Tom Bailey 1994, pers. comm., United States Forest Service, Roanoke, Virginia).

There were no significant differences ($\alpha$ = .05 level) in site quality of the treatments as indicated by site index and Forest Site Quality Index (FSQI) (Wathan 1977) values (Table 1). In general, site quality is greater for Clinch than for the Blacksburg and Fishburn sites (Table 1).

**Site Histories**

According to Proco (1994), early cutting in the Fishburn area began around 1840 to 1850, and by the early 1900's the timber supply had largely been depleted. Since the 1920's the vegetation in the area has been relatively undisturbed (Proco 1994). However, overstory damage occurred on the Fishburn tract as a result of the ice storm of 1994. While damage was evident in the Understory Vegetation Control treatment plot prior to site selection, little damage, if any, was noted on the Control treatment plot.

The U.S. Forest Service acquired the area in which the Blacksburg site is located in the early 1940's. While no detailed records exist regarding the history of the Blacksburg site, aerial photographs were available which dated back to 1935. The 1935 aerial photos showed a relatively continuous canopy, with poletimber-sized crowns. Although the resolution of the 1935 photos was poor, there appeared to be some small gaps in the canopy. The 1967 and 1981 photos showed that the canopy remained relatively continuous, although some gaps in the canopy could still be seen.

The area in which the Clinch site is located was periodically highgraded from approximately the late 1800's to the early 1900's. The most recent logging in the area occurred sometime between 1920 and 1930, corresponding to the time of the chestnut blight (Ken Branham 1994, pers. comm., United States Forest Service, Wise, Virginia).

**Overstory Characteristics**

The Fishburn site pretreatment overstory density was 1001 and 556 stems $ha^{-1}$, and mean basal area was 16.5 and 18.6 $m^2$ $ha^{-1}$, for the Control and UVC plots, respectively (Table 2). The majority of the basal area for the UVC plot was made up of chestnut oak, scarlet oak, and white oak; scarlet oak, white oak, and black oak comprised the majority of the basal area on the Control plot (Appendix B, Tables 1 and 2). For the Blacksburg site, the pretreatment overstory density was 747 and 1007 stems $ha^{-1}$, and mean basal area was 20.7 and 30.7 $m^2$ $ha^{-1}$ for the Control and UVC plots,

**Table 2.** Overstory (stems > 5 m tall) characteristics for the Understory Vegetation Control (UVC) and Control (CON) treatments for the Blacksburg, Clinch, and Fishburn study sites located in southwest Virginia.

| Site | Overstory Density (stems $ha^{-1}$) | | Overstory Basal Area ($m^2$ $ha^{-1}$) | |
|---|---|---|---|---|
| | UVC | CON | UVC | CON |
| Blacksburg | 1007 | 747 | 30.7 | 20.7 |
| Clinch | 776 | 729 | 30.3 | 28.4 |
| Fishburn | 556 | 1001 | 18.6 | 16.5 |
| **Mean:** | **779**[1] | **825** | **26.5** | **21.9** |
| **P-value** | **.2223** | | **.8460** | |

[1] Comparisons between treatments from ANOVA followed by Fisher's LSD.

respectively (Table 2). The majority of the basal area for both plots was made up of chestnut oak, scarlet oak, and white oak in varying proportions (Appendix B, Tables 3 and 4). The Clinch site overstory had a mean density of 729 and 776 stems $ha^{-1}$ and a mean basal area 28.4 and 30.3 $m^2$ $ha^{-1}$ prior to treatment, for the Control and UVC plots respectively (Table 2). The basal area for the UVC plot was primarily comprised of northern red oak, red maple, and white oak. Northern red oak, black gum, and chestnut oak made up the majority of the basal area on the Control plot (Appendix B, Tables 5 and 6).

Across the three study sites, overstory structure and species composition were similar for the two treatments, although the mean diameter was slightly larger for the UVC plots (Table 3). White oak, scarlet oak, chestnut oak, and northern red oak comprised the majority of the average basal area for the two treatments (Table 3).

**Assignment of Treatments to Treatment Plots**

Treatments were randomly assigned to each of two 2 ha treatment plots at each of the three study sites. As was previously mentioned, the treatments of interest in this study include the Understory Vegetation Control and Control (no silvicultural manipulation).

**Table 3.** Pretreatment overstory (stems > 5 meters in height) relative density (RELDEN) and relative basal area (RELBA) by species for Understory Vegetation Control (UVC) and Control treatments for medium quality sites in southwest Virginia.

| Species | UVC | | Control | |
|---|---|---|---|---|
| | ------- % ------- | | ------- % ------- | |
| | RELDEN | RELBA | RELDEN | RELBA |
| White oak[1] | 19.2 | 26.4 | 13.0 | 26.7 |
| Scarlet oak | 7.5 | 16.1 | 6.4 | 12.7 |
| Chestnut oak | 16.1 | 16.4 | 9.3 | 15.2 |
| Northern red oak | 4.5 | 10.2 | 5.3 | 8.3 |
| Black oak | 2.4 | 3.8 | 6.3 | 10.5 |
| Red maple | 16.3 | 6.9 | 16.8 | 3.8 |
| Downy serviceberry | 8.3 | 2.4 | 5.5 | 1.4 |
| Pignut hickory | 1.4 | 1.0 | 2.2 | 0.6 |
| Mockernut hickory | 6.8 | 2.2 | 6.7 | 1.8 |
| Fraser magnolia | 0.2 | 0.1 | 4.8 | 1.8 |
| Blackgum | 2.4 | 1.3 | 5.7 | 7.8 |
| Sourwood | 2.0 | 2.2 | 3.2 | 2.9 |
| Pitch pine | 1.1 | 3.6 | 0.3 | 0.9 |
| White pine | 5.9 | 4.4 | 0.2 | 0.4 |
| White ash | 0.3 | 0.0 | 0.8 | 0.1 |
| Cucumbertree | 0.2 | 0.6 | 0.3 | 0.1 |
| Post oak | 0.3 | 0.3 | 2.1 | 0.6 |
| Other species[2] | 5.1 | 2.1 | 11.1 | 4.4 |
| | Stems $ha^{-1}$ | $m^2$ $ha^{-1}$ | Stems $ha^{-1}$ | $m^2$ $ha^{-1}$ |
| All species | 779 | 26.5 | 825 | 21.9 |

[1] Scientific names are provided in Appendix C.

[2] Includes the following species: witch hazel, black birch, sassafras, black cherry, southern red oak, flowering dogwood, American chestnut, sugar maple, mountain winterberry, black locust, and Virginia pine.

**Location and Design of Sample Plots**

Within each of the treatment plots being studied 3, 24 x 24 meter (576 $m^2$) overstory subplots (OSPs) were randomly located. Twenty (20) 9 $m^2$ circular understory subplots (USPs) were located on a systematic random grid, for a total of 120 subplots across all three sites. One (1) 1 $m^2$ square understory sub-subplot (USSP) was located adjacent to each of the 9 $m^2$ subplots.

Overstory subplots were permanently located using 0.7 m sections of PVC pipe placed over 0.5 m sections of re-bar for the 4 corners and center of the plot. Other PVC pipes were used to further divide the subplot for the purposes of the diversity study, with the exception of the Fishburn site where only the corners and center were permanently located (Figure 2). The overstory subplots were located such that the plot boundaries ran north-south and east-west (Figure 2). Understory subplot (9 $m^2$ plot) centers were permanently marked with 0.7 m sections of 1.25 cm PVC pipe placed over 0.5 m pieces of 1 cm re-bar driven into the ground. The center of each 9 $m^2$ USP was tagged with aluminum write-on tags marked with a numeric code so they may be easily distinguished from other plots in the future. Each USSP was located at one of four randomly chosen azimuths (45, 135, 225, and 315 degrees) from the respective USP plot center (Figure 3). Two corners were permanently marked for each

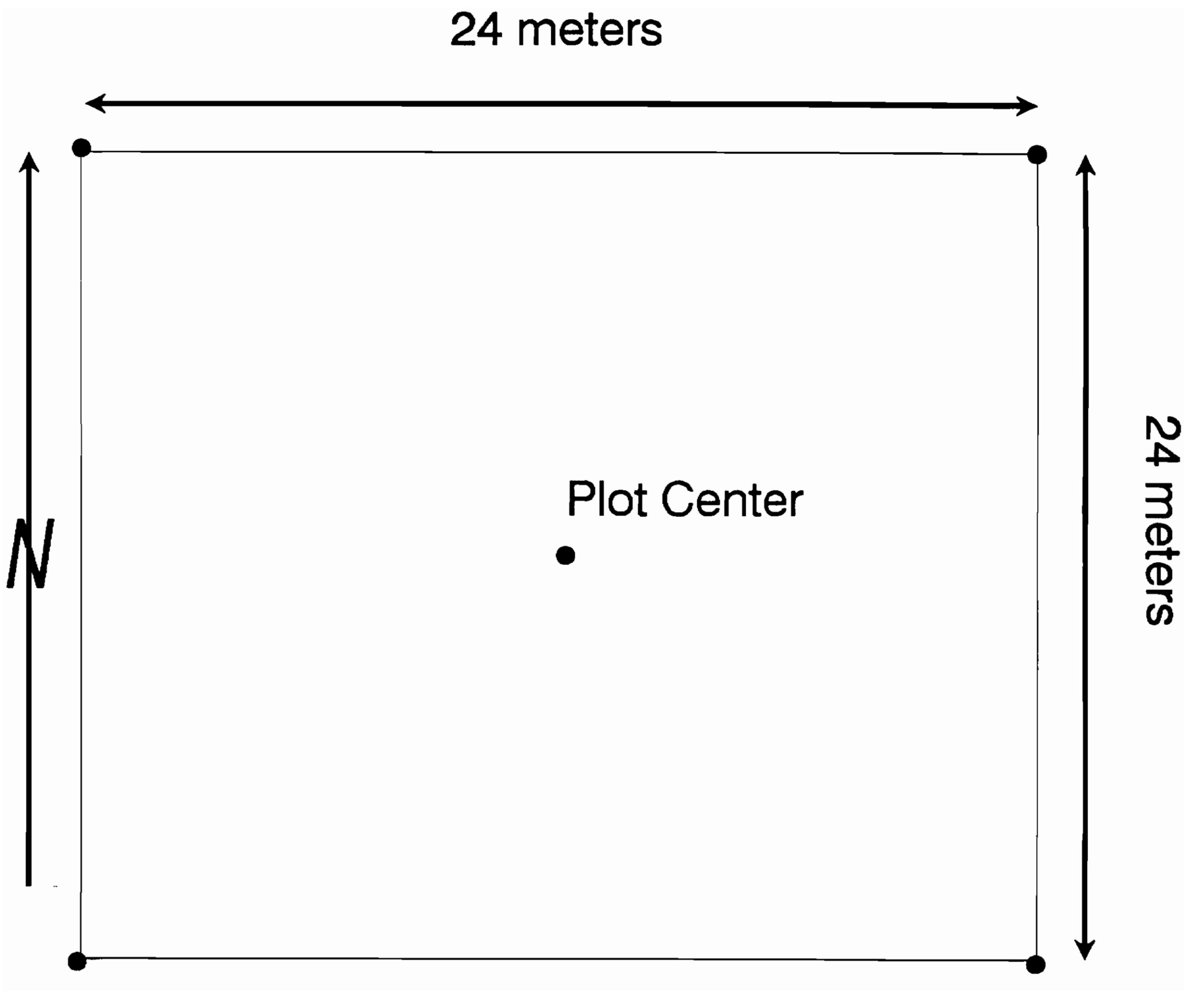


**Figure 2.** Configuration of the 24 x 24 m overstory subplots. Three such plots are randomly located about the center of each 5 acre treatment plot.

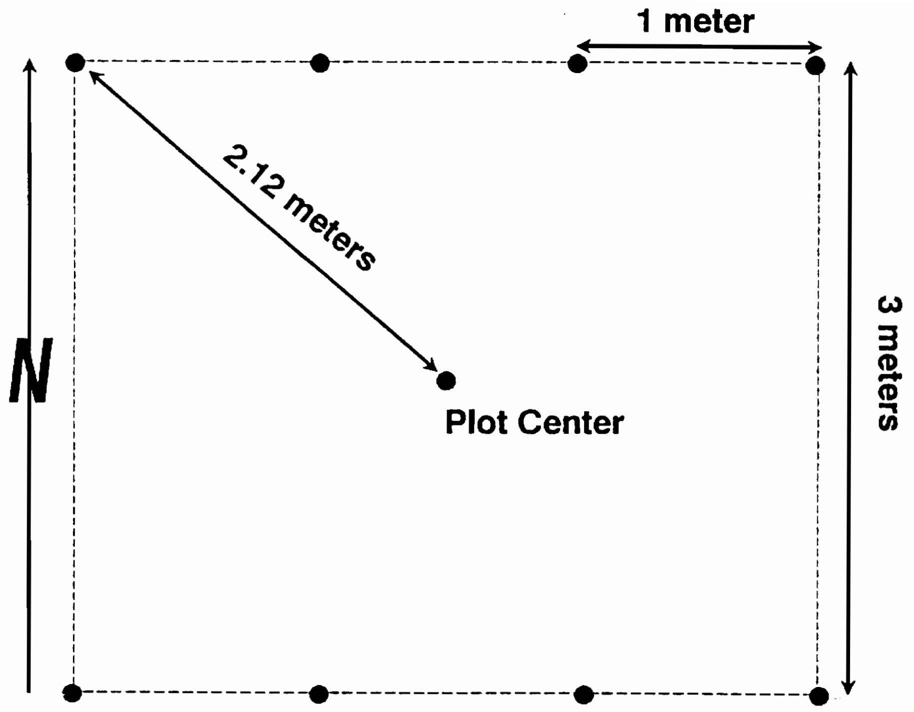


**Figure 3.** Configuration of the 9 $m^2$ understory subplots and 1 $m^2$ understory sub-subplots. Note that the only permanent feature of the 9 $m^2$ plot is the plot center. Twenty such plots were located on a systematic random grid within each 5 acre treatment plot.

USSP, where the first corner was located 2.12 m from the respective USP plot center and the second corner was located 1 meter from the first so that the two corners were oriented east-west (Figure 3). For measurement, a 1 x 1 m grid was placed on the two corners such that the inside of the plot was closest to the USP center. USSP corners were permanently located using 0.7 m sections of 1.25 cm PVC pipe.

**Measurement of Sample Plots**

Woody vegetation was separated into 4 vertical strata: 1) > 5 m , 2) 2 - 5 m, 3) 1 - 2 m, and 4) 0 - 1 m in height. Stratum 1 stems were measured in the 576 $m^2$ overstory subplots and strata 2 and 3 stems were measured in the 9 $m^2$ understory subplots. Stratum 4 stems were measured in the 1 $m^2$ understory sub-subplots. The purposes of separating woody stems into various strata were to ensure sampling of the individual stems across a range of stem heights (for strata 1 and 2) and to aid in determining if survival and/or height growth of the individuals was correlated with stem height.

In each of the 24 x 24 m overstory subplots the species and diameter were recorded for each tree greater than 5 meters in height located within the plot. In each 9 $m^2$ subplot a stem count was done, by species, of all woody stems in strata 2 and 3 (Appendix D, Tables 1-3). In the 1

$m^2$ sub-subplots a separate stem count was taken of all new germinants (woody stems less than one year of age) and woody stems > 1 yr to 1 m in height for stratum 4 in order to determine recruitment and density of small woody regeneration, respectively (Appendix D, Tables 4-6). Also, herbaceous cover class (all species) and fern cover class (by species) was ocularly estimated in each 1 x 1 m plot using pretransformed percentages (Figure 4). Slope, aspect, and slope position was taken across the regeneration subplot center to determine FSQI (Appendix E). Slope and aspect were measured using a clinometer and compass, respectively. Site index (base age 50 for upland oak) was determined for each treatment plot by taking an increment core sample (at breast height) and height to the nearest 0.3 m, using a clinometer, on three dominant or codominant white oak trees per treatment plot. It should be noted that the site index values determined for each of the three sites were probably underestimated by an unknown amount because present dominant and codominant stems were in all likelihood not free-to-grow throughout the course of their development, which is required for site index readings to be accurate.

**Location and Measurement of Individual Seedlings**

Individual seedlings were monitored such that the following factorial combinations were achieved, where

| Ground Cover Class | Range | Example |
|---|---|---|
| 1 | 0 - 7% | 7% |
| 2 | 8 - 25% | 25% |
| 3 | 26 - 50% | 50% |
| 4 | 51 - 75% | 75% |
| 5 | 76 - 93% | 93% |
| 6 | 94 - 100% | 100% |

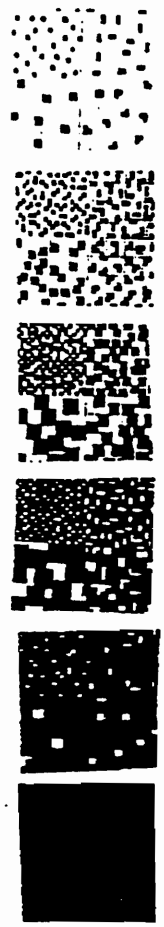

**Figure 4.** Ground cover classes for estimating the percent of a sampling plot occupied by woody and/or herbaceous species leaf area.

20 stems per species/strata combination was the desired number of seedlings to be monitored (for a total of 720 seedlings across the 3 sites):

| **3 Sites** | x | **2 Treatments** | x | **3 Species Groups** | x | **2 Strata** |
|---|---|---|---|---|---|---|
| ■ Blacksburg | | ■ UVC | | ■ Maples | | ■ 0 - 1 m |
| ■ Clinch | | ■ Control | | ■ Red oaks | | ■ 1 - 2 m. |
| ■ Fishburn | | | | ■ White oaks | | |

The number of seedlings actually located for each species group/strata combination varied from 1 to 32 due to the scarcity of oak stems greater than 1 m tall and the incorrect placement of seedlings less than 1 m tall into the 1 to 2 m height class (Table 4). The number of seedlings located prior to treatment was 238, 218, and 232 for the Blacksburg, Clinch, and Fishburn sites, respectively, for a grand total of 688 seedlings (Table 4). Species groups were used to ensure an adequate number of seedlings to monitor. All seedlings were recorded to the species level, however, and included the following: maple group: *Acer rubrum* and *A. saccharum* (very few); white oak group: *Quercus alba* and *Q. prinus*; red oak group: *Q. rubra*, *Q. coccinea*, *Q. illicifolia* (very few).

One individual seedling for each species group/strata combination (6 in all) was located near each of the 20, understory subplots (at each of the three sites) such that the closest stem, of each combination, to the subplot center

**Table 4.** Number of individual seedlings 0 - 1 and 1 - 2 meters tall located prior to treatment by Site and Species Group for Understory Vegetation Control (UVC) and Control treatments in mixed oak stands in southwest Virginia.

| Site | Maple UVC | Maple Control | Red Oak UVC | Red Oak Control | White Oak UVC | White Oak Control | Total |
|---|---|---|---|---|---|---|---|
| | **0 to 1 meter tall** | | | | | | |
| Blacksburg | 26 | 22 | 26 | 22 | 29 | 23 | 148 |
| Clinch | 22 | 20 | 31 | 25 | 32 | 21 | 151 |
| Fishburn | 22 | 22 | 25 | 25 | 21 | 20 | 135 |
| **Total** | **70** | **64** | **82** | **72** | **82** | **64** | **434** |
| | **1 to 2 meters tall** | | | | | | |
| Blacksburg | 12 | 17 | 12 | 18 | 11 | 20 | 90 |
| Clinch | 16 | 20 | 2 | 15 | 1 | 13 | 67 |
| Fishburn | 16 | 17 | 15 | 14 | 17 | 18 | 97 |
| **Total** | **44** | **54** | **29** | **47** | **29** | **51** | **254** |

was chosen. Distance and azimuth to each seedling from the subplot center was recorded to aid in relocation. Seedlings were marked with a numbered aluminum tag, attached at either the base or on a limb using heavy-duty wire. The wire was looped about the portion of each stem so that it was secure, but allowed enough room for growth. Care was taken to ensure that a range of stem heights was chosen within each strata for each species. If a stem corresponding to any species x strata combination could not be located within 12 to 15 m of any subplot center then it was located adjacent to one of the other subplots at each site.

Measurements on individual seedlings included species; total height, measured on the uphill side of the stem, to the nearest cm; groundline diameter to the nearest 0.1 mm using a caliper; stem origin for stems in stratum 1 (and stratum 2, if possible); level of woody competition within a 1.5 m radius: density (by 0.1 m height classes) of all arborescent and other woody stems less than or equal to 2 m tall (as specified in Special Sampling Situations: Appendix F) and the density of stems in the following two height classes: 2 to 5 m and greater than 5 m (Table 5). The level of herbaceous (all species) competition within a 1.5 m radius of the seedling base was estimating using pre-transformed cover classes (Figure 3). Overhead canopy cover about the center and above the crown of each seedling was

**Table 5.** Measurements taken on individual seedlings.

Species

Height (nearest cm)

Groundline diameter (.1 mm)

Origin (Seedling, Seedling Sprout, or Stump Sprout)

Competing vegetation within 1.5 m of seedling base:

- Density of stems ≤ 2 m tall by 10 cm height classes
- Density of stems 2 to 5 m tall
- Density of stems 5 m tall
- Herbaceous cover (pre-transformed percentages)

Overhead canopy cover

Overstory basal area

Seedling condition (Posttreatment only):

- 0: Dead
- 1: Live (with no apparent damage)
- 2: Partial top dieback
- 3: Complete top dieback (with resprout)
- 4: Mechanical damage
- 5: Animal browse
- 6: Missing or could not locate
- 7: Herbicide damage
- 8: Damage caused by harvesting or road-building

measured with a convex spherical densiometer at the 4 cardinal directions (north, south, east and west). In addition to these measurements, overstory basal area per acre (BAA) was determined about each stem using a 10 BAF prism (Table 5).

For posttreatment data collection, each seedling was given a condition code (Table 5). The condition codes given were as follows: 0: dead (not a result of herbicide damage), 1: live (with no apparent damage), 2: partial top dieback, 3: complete top dieback with resprout, 4: mechanical damage (e.g. tree fell on seedling), 5: animal browse, 6: missing or could not locate, 7: herbicide damage (though not necessarily dead), and 8: damage caused by road building or harvesting operations. The assignment of a code to each seedling was done so that percent mortality, or other damage, could be calculated.

**Treatment Implementation**

The understory vegetation control treatment was implemented using the streamline (individual stem) basal application method with triclopyr (13.6% a.i. or 0.09 kg a.e./l solution of Garlon 4) in a methyl oleate carrier applied at a rate of approximately 1.2 ml per cm of stem diameter. The methyl oleate carrier used in the present study was supplied by two manufacturers. Each manufacturer's carrier was applied to half of each of the three understory vegetation control plots. The use of the different manufacturers carriers was a part of a sub-study to test for any differences in efficacy between the two methyl oleate carriers. Visual inspection showed no differences in efficacy for the two manufacturer's carriers.

To meet the treatment objectives of quantifying the effects of understory vegetation removal on the competitive status of existing advance regeneration and the recruitment of new regeneration, the following treatment guidelines were established:

1) All stems between 1 and 5 meters in height not listed as one of the top 14 species in the Preferred Species List (Appendix A) were treated.

2) Stems not listed as one of the 14 preferred species in the overtopped or suppressed canopy position not capable of becoming a vigorous main canopy tree in the future were also chemically controlled. Note: If the tree was greater than 10 cm dbh then the hack-and-squirt treatment method was used.

3) Overstory basal area was not manipulated.

4) Stems less than 1 meter in height were not controlled.

The number of stems treated at each site using the above guidelines was approximately 1,267, 2,426, and 2,152 stems per hectare for the Blacksburg, Fishburn, and Clinch sites, respectively, as estimated from pretreatment data collected at each site (Appendix D, Tables 1 and 3). The amount of solution applied at the Blacksburg, Fishburn, and Clinch sites was 4.2, 5.6, and 4.2 l/ha, respectively. The corresponding amount of acid equivalent (a.e.) of Triclopyr ester applied at the Blacksburg, Fishburn, and Clinch sites was found to be 0.38, 0.50, and 0.38 kg a.e./ha, respectively. The estimated cost for this treatment, including labor and ready to use (RTU) chemical was approximately $133.00 per hectare (@ 1,853 treated stems per hectare, 15 hr per person per hectare, $7.00 per hour wages, and $7.40 per l RTU chemical). The cost could be lower depending on the number of stems treated; treatment cost could also be lower if a spot treatment method is used.

Due to a lack of efficacy on species such as blackgum (*Nyssa sylvatica* Marsh.), flowering dogwood (*Cornus florida* L.), mountain winterberry (*Ilex verticillata* (L.) Gray) and *Magnolia* spp. L., a follow-up treatment was performed at each site between late May and early June of 1995. This follow-up treatment was implemented using the hack and squirt method with picloram + 2,4-D (10.2% a.i./l or 0.24 kg a.e./l undiluted Tordon 101 mixture) at a rate of 0.2 ml per cm diameter. Approximately 553, 827, and 165 stems $ha^{-1}$ were treated at the Blacksburg, Fishburn, and Clinch sites with the hack and squirt method, for an approximate average cost of $45.00 per hectare (@ 515 treated stems per hectare, 4 hr per person per hectare, $7.00 per hour wages, and $8.00 per l RTU chemical).

**Data Analysis**

Before any statistical comparisons were made, the samples being compared were tested for normality using the Shapiro-Wilks test. For this test the following hypotheses were used:

> $H_o$: The data comes from a population which is normally distributed.
>
> $H_a$: The data come from a population which is not normally distributed.

All parametric statistical procedures operate on the assumption that the data being tested come from a population that is normally distributed. The validity of the stated alpha level and power of each procedure are dependent on the normality assumption and are altered if the normality assumption is incorrectly made. The majority of the data were found to be non-normal. Parametric analyses were used regardless of the presence of non-normal data, therefore it should be recognized that the alpha level of the tests cannot be considered highly accurate.

In addition, the data being compared were tested for equal variance using PROC TTEST (SAS Institute 1985). The following hypotheses were used for this test:

$H_o$: The population variances are equal.

$H_a$: Not all the population variances are the same.

If the null hypothesis was rejected in favor of the alternative hypothesis then the data was transformed using the most appropriate transformation for the data in question.

**Seedling Analyses**

Analysis of the individual stems (seedlings) was partitioned into two main types: 1) seedling condition analyses and 2) seedling growth analyses. These analyses were performed for a Randomized Complete Block (RCB) design using Analysis of Variance (ANOVA) followed by Fisher's LSD test. All analyses were performed by species group (Maple, Red Oak, or White Oak), with the experimental unit for all ANOVA analyses being the 2 ha treatment plot.

***Seedling Condition***

The analysis of the seedling condition data focused on answering the following questions: 1) did mortality differ between the two treatments or height classes, and 2) did the percentage of stems with top dieback (both partial and complete) differ between the two treatments or height classes? All analyses were performed on square root transformed percentages to correct for unequal variance. Seedlings with the following condition codes were excluded from the analyses: 4: mechanical damage (e.g. tree fell on seedling), 6: missing or could not locate, and 8: damage caused by road-building or harvesting operations. A total of 677 seedlings (of the original 688 seedlings) were included in the analyses across 3 sites, 2 treatments, 3 species groups, and 2 height classes.

***Seedling Growth and Competing Vegetation***

The analysis of the seedling growth and competition data was directed at answering the following questions: 1) was the understory vegetation control treatment effective in reducing the level of competing vegetation, 2) does seedling growth differ between the treatments, and 3) what is the relationship between seedling growth and competing vegetation, initial groundline diameter ($D_{1994}$), and canopy cover? For these analyses only seedlings with a condition of 1: live (with no apparent damage) were included, for a total of 576 seedlings (of the original 688 seedlings) across 3 sites, 2 treatments, 3 species groups, and 2 height classes.

To determine if seedling growth differed between the treatments, an ANOVA for a RCB design followed by Fisher's

LSD was performed on both relative and absolute seedling growth. Relative seedling growth was calculated in the following manner:

$$\frac{Height_{1995}-Height_{1994}}{Height_{1994}}$$

Height growth values were not transformed due to the presence of negative values.

To determine the relationship between seedling growth and the following competing vegetation variables:

**SH05**: the sum of the heights, in meters, of competing stems between 0 and 5 meters in height within 1.5 meters of seedling,

**SH15**: the sum of the heights, in meters, of competing stems between 1 and 5 meters in height within 1.5 meters of seedling,

**SHGSH**: the sum of the heights, in meters, of competing stems greater than or equal to seedling height within 1.5 meters of seedling,

**CS05**: the number of competing stems between 0 and 5 meters in height within 1.5 meters of seedling,

**CS15**: the number of competing stems between 1 and 5 meters in height within 1.5 meters of seedling, and

**CSGSH**: the Sum of the Heights, in meters, of competing stems Greater than or equal to Seedling Height,

correlation analysis was performed using PROC CORR (SAS Institute 1985). Correlation analysis was also performed on groundline diameter, the ratio of seedling height to groundline diameter (HDR), and percent overhead (canopy) cover (CCOV) to determine their relationship with height growth. For the correlation analyses only seedlings with a condition of 1: live (with no apparent damage) were included. The analyses were performed by species group, with 196, 201, and 179 seedlings being used for the maple, red oak, and white oak species groups, respectively. The data from the two treatments were grouped together due to the lack of significant differences for seedling height growth between the two treatments from ANOVA.

To determine if the UVC treatment was effective in reducing the level of competing vegetation around the seedlings of interest, statistical analysis was performed on the competition variable SH15 using ANOVA for a RCB design, followed by Fisher's LSD test. Because significant pretreatment differences ($\alpha$ = .1 level) were found between the treatments, both absolute ($\Delta$SH15) and relative change (R$\Delta$SH15) in the competition variable SH15 were analyzed. Analyses were performed on the untransformed data, due to the presence of negative values.

Relative change was calculated for the competition variable SH15 in the following manner:

$$\frac{SH15_{1995} - SH15_{1994}}{SH15_{1994}}$$

**Abundance (Plot) Data Analyses**

The analysis of the plot sampling data focused on answering the following questions: 1) was the treatment effective in enhancing seedling recruitment for *Quercus* spp. and 2) was the treatment effective in increasing the relative abundance of *Quercus* spp. advance regeneration in the following height classes: 1) 0 to 1 meter (greater than or equal to one year old), 2) 1 to 2 meter, and 3) 2 to 5 meter?

Analysis of variance (ANOVA) for a Randomized Complete Block (RCB) design followed by Fisher's LSD test was performed on relative number of stems per ha for both pre- and post-treatment data to answer the above questions. Analyses were performed on square root transformed percentages or $\log_{10}$ transformed densities to correct for unequal variance. All analyses were performed by species, with the experimental unit being the treatment plot as in the individual stem analyses.

## RESULTS and DISCUSSION

### Effect of Understory Vegetation Control on Competing Vegetation

The pretreatment level of competing vegetation around tagged seedlings was significantly lower for the Understory Vegetation Control (UVC) plots than for the Control plots for the following three competition variables: 1) sum of the heights of competing stems 0 to 5 m tall (SH05) (14.3 vs. 19.2 m, P = .0013); 2) sum of the heights of competing stems greater than or equal to seedling height (SHGSH) (5.6 vs. 9.3 m, P = .0002); and the sum of the heights of competing stems 1 to 5 m tall (SH15) (4.9 vs. 8.4 m, P = .0001) (Table 6). However, the treated strata of competing vegetation (stems 1 to 5 m tall) was significantly reduced by the UVC treatment (P = .0001), where the relative change in SH15 was -15.9 percent for the UVC plots and 22.8 percent for the Control plots one year after treatment (Table 6). While no other studies involving the removal of understory and midstory vegetation have reported treatment effects on competing vegetation, pretreatment levels of understory vegetation have been reported in some cases. Lorimer *et al.* (1994) reported pretreatment small understory tree (≥ 1 m tall and ≤ 5 cm DBH) densities between 3,159 and 6,274 stems per hectare in mesic oak stands in Wisconsin. Similar

**Table 6.** Mean pretreatment level of competing vegetation within 1.5 meters of seedling base by height class of competitors and the relative change in the sum of the heights of competing stems between 1 and 5 meters in height one year after treatment for Understory Vegetation Control (UVC) and Control treatments in mixed oak stands in southwest Virginia.

| Treatment | SH05[1] | SHGSH[2] | SH15[3] | RΔSH15[4] |
|---|---|---|---|---|
| | ---------- | meters | ---------- | -- % -- |
| UVC | 14.3[4] | 5.6 | 4.9 | - 15.9 |
| Control | 19.2 | 9.3 | 8.4 | 22.8 |
| P-value | .0013 | .0002 | .0001 | .0001 |

[1] Sum of the heights of competing stems between 0 and 5 meters in height(SH05).

[2] Sum of the heights of competing stems greater than seedling height to 5 meters in height (SHGSH).

[3] Sum of the heights of competing stems between 1 and 5 meters in height (SH15), or the treated strata of competing vegetation in the UVC plots.

[4] Relative change in the sum of the heights of competing stems between 1 and 5 meters in height one year after treatment (RΔSH15).

[5] Statistical analyses were performed on log transformed values for absolute data and on square root transformed values for percentage data (ANOVA, followed by Fisher's LSD).

density values were observed in the present study, where 3,138 and 5,583 stems 1 to 5 m tall per hectare were found in the UVC and Control plots, respectively, prior to treatment (Table 7). The greater pretreatment density of competing vegetation noted in the Control plots is likely due to the higher average site quality ($SI_{50}$ 18.9 vs. 20.4 m for upland oak, P = .0926) and lower overstory (stems > 5 m tall) basal area (21.9 vs. 26.5 $m^2$ $ha^{-1}$, P = .8460) of the Control plots relative to the UVC plots (Tables 1 and 2).

## Seedling Condition

### Mortality

Percent mortality of tagged seedlings was found to be significantly greater in the UVC treatment for maple group seedlings (4.0 vs. 1.6 percent, P = .0984) (Table 8). While not statistically significant, red oak and white oak group seedlings exhibited lower mortality in the UVC treatment than in the Control (0.0 vs. 2.2, P = .1008 and 3.8 vs. 8.4, P = .2199, respectively) (Table 8). Percent mortality was consistently lower for seedlings in the 1 to 2 m height class for seedlings in all three species groups (1.0 vs. 4.6 percent, P = .0174; 0.0 vs. 2.2, P = .1008; and 3.8 vs. 8.5, P = .1046 for maple, red oak, and white oak group seedlings, respectively) (Table 8). The lower P-values associated with height class compared to those for treatment for each

**Table 7.** Pretreatment and Posttreatment mean density and percent change of competing vegetation between 1 and 5 meters tall for Understory Vegetation Control (UVC) and Control treatments in mixed oak stands in southwest Virginia.

| Treatment | ----------- Density ------------- Pretreatment | Posttreatment | Percent Change |
|---|---|---|---|
| | -------stems per | hectare-------- | -- % -- |
| UVC | 3,138[1] | 1,957 | -37.6 |
| Control | 5,584 | 6,074 | 8.8 |
| P-value | .0001 | .0001 | |

[1] Statistical analyses performed on log transformed values (ANOVA, followed by Fisher's LSD).

**Table 8.** Percent seedling mortality one year after treatment by species group for Understory Vegetation Control (UVC) and Control treatments and 0 to 1 m and 1 to 2 m height classes for mixed oak stands in southwest Virginia.

| Treatment/ Height Class | Maple | Red Oak | White Oak |
|---|---|---|---|
| | ---------- | % | ---------- |
| UVC | 4.0[1] | 0.0 | 3.8 |
| Control | 1.6 | 2.2 | 8.4 |
| **P-value** | **.0984** | **.1008** | **.2199** |
| 0 to 1 m | 4.6 | 2.2 | 8.5 |
| 1 to 2 m | 1.0 | 0.0 | 3.8 |
| **P-value** | **.0174** | **.1008** | **.1046** |

[1] Statistical analyses were performed on square root transformed percentages (ANOVA, followed by Fisher's LSD). The number of seedlings included in the subsample for the analyses was similar for the UVC and Control Treatments; the 0 to 1 m height class had a greater number of seedlings included in the analysis than did the 1 to 2 m height class, however (Appendix G, Table 1).

species group indicate a stronger statistical relationship between height class and seedling mortality than treatment and seedling mortality (Table 8). The greater mortality of maple seedlings in the UVC plots can, in part, be explained by overspray during treatment application (Table 8).

In a Missouri study where three levels of overstory reduction (40, 50, and 60 percent stocking retained) were combined with three levels of understory reduction (heavy, medium, and light reduction), seedling survival four years after treatment ranged between 63 and 91 percent on good ($SI_{50}$ 22.9 to 25.9 m for black oak) sites and between 62 to 84 percent on average ($SI_{50}$ 16.8 to 19.8 m for black oak) sites (Sander 1987). Seedling survival was unrelated to treatment in the Missouri study (Sander 1987). The results of the present study show a similar trend, where seedling survival is not related to manipulation of competing vegetation, but rather to pretreatment seedling height (Table 8). Larger seedlings have larger root systems which allows for not only better growth, but increased chance for survival (Sander 1972).

While several studies have reported improved survival for oak seedlings following understory or midstory vegetation reduction (Deen *et al.* 1993, Lockhart *et al.* 1993, Lorimer *et al.* 1994), not all understory reduction treatments have resulted in improved survival. In a North

Carolina study, red oak seedling survival after nine years was 25 percent with a treated subcanopy and 22 percent with the subcanopy untreated (Loftis 1990a). Another study in North Carolina reported survival rates between 40 and 60 percent for seedlings released from low vegetation (1.37 m or less in height) and survival between 20 and 24 percent for unreleased seedlings after six growing seasons; however, the differences in the treatments were not statistically significant (Beck 1970).

Few studies have reported mortality or survival data one year after treatment for natural oak seedlings. In a bottomland hardwood study of two sites in east-central Mississippi, survival rates one year after treatment for cherrybark oak were approximately 80 and 90 percent for seedlings in the midstory-understory reduction treatment and approximately 80 and 100 percent for unreleased seedlings (Lockhart et al. 1993). In a North Carolina study, Beck (1970) reported new oak seedling survival after one year in excess of 90 percent for both released and unreleased seedlings. The results of the present study are similar, where seedling survival exceeded 90 percent for both treatments and height classes for the maple, red oak, and white oak species groups.

**Partial and Complete Top Dieback**

The percent of tagged seedlings with Partial Top Dieback (PTD) or Complete Top Dieback with Resprout (CTDR) did not differ significantly between any of the main effects of Treatment, Species Group, or Height Class (Tables 9 and 10). However, mean values show the white oak group seedlings to have a greater percentage of seedlings with PTD than maple or red oak group seedlings (Table 11). In addition, red oak and white oak seedlings had a greater percentage of seedlings with CTDR than maple seedlings, which suggests greater shade tolerance for maple seedlings. Maple seedlings had lower mean height of competing stems (0 to 5 m tall) than did the red oak and white oak seedlings (8.3 m vs. 17.2 and 11.9 m, respectively) (Table 11). While the extent of top dieback does not seem to be related to the pretreatment means of height or groundline diameter, seedlings with CTDR had higher mean densities of competing stems 0 to 5 m tall (CS05) than seedlings with PTD (Table 11). The propensity of oak seedlings to dieback and resprout is commonly recognized and allows for the build-up of advance regeneration under forest stands over time (Watt 1979, Burns and Honkala 1990).

Liming and Johnson (1944), in their study of 4,800 small oaks in Missouri, determined that nearly 80 percent were seedling sprouts and that no true seedlings older than 7 years were found. Of the seedlings located prior to

**Table 9.** Partial ANOVA table for a Factorial Experiment with a Randomized Complete Block Design for percent of seedlings with Partial Top Dieback[1].

| Source | d.f. | F-value | Pr > F |
|---|---|---|---|
| Site (Block) | 2 | 0.51 | .6066 |
| Treatment (A) | 1 | 2.37 | .1380 |
| Species Group (B) | 2 | 1.58 | .2288 |
| Height Class (C) | 1 | 0.67 | .4219 |
| A x B | 2 | 0.26 | .7740 |
| B x C | 2 | 0.41 | .6700 |
| A x C | 1 | 0.05 | .8251 |
| A x B x C | 2 | 1.76 | .1957 |

[1] Statistical analysis was performed on square root transformed percentages.

**Table 10.** Partial ANOVA table for a Factorial Experiment with a Randomized Complete Block Design for percent of seedlings with Complete Top Dieback and Resprout[1].

| Source | d.f. | F-value | Pr > F |
|---|---|---|---|
| Site (Block) | 2 | 2.75 | .0862 |
| Treatment (A) | 1 | 0.01 | .9114 |
| Species Group (B) | 2 | 0.72 | .4996 |
| Height Class (C) | 1 | 0.23 | .6374 |
| A x B | 2 | 0.55 | .5829 |
| B x C | 2 | 0.81 | .4592 |
| A x C | 1 | 1.41 | .2475 |
| A x B x C | 2 | 1.80 | .1893 |

[1] Statistical analysis was performed on square root transformed percentages.

**Table 11.** Percent of seedlings with Partial Top Dieback (PTD) and Complete Top Dieback with Resprout (CTDR) by species group with respective mean pretreatment seedling characteristics for mixed oak stands in southwest Virginia.

| Species Group[1] | Dieback Type | Percent of seedlings with dieback[2] | ---- seedling characteristics ----- Height (cm) | GLD[3] (cm) | SH05[4] (m) | CS05[5] stems ha$^{-1}$ |
|---|---|---|---|---|---|---|
| Maple (228) | - Partial | 5.1 (1.1) | 89 (16) | 1.15 (0.20) | 18.8 (3.0) | 55,707 (10,759) |
| | - Complete | 1.4 (0.7) | 59 (40) | 0.70 (0.33) | 8.3 (3.1) | 64,480 (11,787) |
| Red Oak (225) | - Partial | 4.1 (1.4) | 64 (13) | 1.29 (0.28) | 13.9 (2.7) | 46,313 (6,067) |
| | - Complete | 4.0 (1.8) | 81 (19) | 1.20 (0.23) | 17.2 (3.3) | 66,363 (11,804) |
| White Oak (224) | - Partial | 8.2 (2.0) | 59 (12) | 0.75 (0.11) | 12.5 (1.3) | 47,872 (3,900) |
| | - Complete | 4.1 (2.3) | 73 (23) | 0.95 (0.21) | 11.9 (2.5) | 69,187 (10,963) |

1 Number of seedlings included in the analysis is given in parentheses.

2 Values shown are means across 3 sites, 2 height classes, and 2 treatments; standard errors are given in parentheses.

3 Groundline diameter (GLD).

4 Sum of the Heights of Competing Stems 0 to 5 meters tall within 1.5 meters of seedling base.

5 Density (stems ha$^{-1}$) of competing stems 0 to 5 meters tall (CS05).

treatment in the present study (688 across all species groups), sprout origin stems (including both seedling sprouts and stump sprouts) accounted for approximately 22, 37, and 35 percent of maple, red oak, and white oak group seedlings, respectively. Seedlings were determined to be true seedlings if the rootstock appeared to be approximately the same size as the above-ground diameter. If the above-ground diameter had grown to a size equal to that of the rootstock diameter after having resprouted, then the stem would have been mistakenly called a true seedling when in fact it was of sprout origin. Therefore, the percent of seedlings classified as true seedlings is likely overestimated for the present study. While seedling sprouts are typically thought to have faster growth rates than true seedlings, the distinction between the two types is likely only significant with regard to differential growth if the difference between rootstock size and shoot size is large. In other words, if the shoot diameter near the base of the stem is the same size as the groundline diameter then the growth advantage of seedling sprouts has likely already been manifested, making the distinction between the two seedling types purely semantic.

## Effect of Understory Vegetation Control on Seedling Growth

**Height Growth**

Understory vegetation control did not improve seedling relative height growth one year after treatment (Table 12). While relative height growth was nearly equal for the UVC and Control treatments for maple group seedlings (3.9 vs. 3.8 percent, respectively, P = .9939), the red oak seedlings exhibited greater growth in the Control plots (6.3 vs. 3.1 percent, P = .6455) and white oak seedlings had greater growth in the UVC plots (6.4 vs. 3.6 percent, P = .5324), though these differences were not statistically significant (Table 12). The differential growth response can be explained by the high relative growth rates of the sprout origin seedlings for the red oak and white oak groups (Table 13). Sprout origin seedlings generally have a more well-developed root system allowing for the potential for greater growth than true seedlings. The data for the sprout origin stems in the present study show greater groundline diameters than the true seedlings, indicating a larger root system is present (Table 13). Similar results were found by Sander (1972), where sprout origin seedlings exhibited greater growth than true seedlings on completely cut, partially cut, and uncut stands in southern Illinois. On the partially cut and uncut stands seedling sprout growth was sluggish, with average heights of less than 1.8 and 1.2 m, respectively,

**Table 12.** Relative seedling height growth one year after treatment and pretreatment seedling height by species group for Understory Vegetation Control (UVC) and Control treatments in mixed oak stands in southwest Virginia.

| Treatment | | Species Group: Maple | Red Oak | White Oak |
|---|---|---|---|---|
| | | --- Relative Height Growth % ---- | | |
| UVC | | 3.9[1] | 3.1 | 6.4 |
| Control | | 3.8 | 6.3 | 3.6 |
| **P-value** | | **.9939** | **.6455** | **.5324** |
| | | ---- Pretreatment Height (cm) ---- | | |
| UVC | Mean | 93.4 | 86.3 | 95.0 |
| Control | Mean | 93.9 | 93.9 | 85.7 |
| **P-value** | | **.7669** | **.3171** | **.0569** |

[1] Means within a column followed by same letter not significantly different at the $\alpha$ = .1 level (ANOVA, followed by Fisher's LSD). The number of seedlings included in the subsample for the analysis was similar for the two treatments (Appendix G, Table 2).

**Table 13.** Mean relative height growth one year after treatment and pretreatment height and Groundline Diameter (GLD) by species group and origin class[1] for Understory Vegetation Control (UVC) and Control (CON) treatments for mixed oak stands in southwest Virginia.

| Treatment | | Maple Seed | Maple Sprout | Red Oak Seed | Red Oak Sprout | White Oak Seed | White Oak Sprout |
|---|---|---|---|---|---|---|---|
| | | Relative Height Growth % | | | | | |
| UVC | Mean | 3.4 | 9.0 | 4.6 | 5.1 | 4.4 | 9.3 |
| | STDERR[2] | 2.2 | 4.2 | 2.1 | 2.2 | 3.7 | 6.2 |
| | (n) | (67) | (25) | (56) | (48) | (51) | (38) |
| CON | Mean | 5.1 | 1.0 | 2.2 | 15.7 | 5.3 | 2.8 |
| | STDERR | 3.0 | 2.3 | 1.8 | 14.6 | 4.9 | 2.1 |
| | (n) | (87) | (17) | (66) | (31) | (67) | (23) |
| | | Pretreatment Height (cm) | | | | | |
| UVC | Mean | 81 | 95 | 59 | 69 | 64 | 88 |
| | STDERR | 7 | 10 | 6 | 6 | 8 | 8 |
| CON | Mean | 86 | 115 | 88 | 95 | 76 | 95 |
| | STDERR | 6 | 16 | 7 | 10 | 7 | 11 |
| | | Pretreatment GLD (cm) | | | | | |
| UVC | Mean | 1.06 | 1.57 | 0.94 | 1.35 | 0.94 | 1.39 |
| | STDERR | 0.09 | 0.20 | 0.10 | 0.14 | 0.11 | 0.15 |
| CON | Mean | 1.00 | 1.70 | 1.22 | 1.50 | 1.00 | 1.55 |
| | STDERR | 0.06 | 0.25 | 0.10 | 0.14 | 0.09 | 0.18 |

[1] Origin Class refers to advance regeneration determined to be of Seedling (Seed) or Sprout origin; Sprout origin includes both seedling sprouts and stump sprouts.

[2] Standard errors (STDERR) given with respective number of seedlings (n) in parentheses.

after 12 years (Sander 1972). Control of understory vegetation was not performed in that study, however.

The lack of early treatment response for height growth in the present study is not uncommon. In a bottomland hardwood study, where midstory and understory vegetation was controlled, red oak (primarily *Quercus nigra* L. and *Quercus phellos* L.) seedling height growth response was delayed for three years after treatment (Deen *et al.* 1993). The average height for released and unreleased seedlings was approximately 92 and 40 cm after seven years, respectively; total height growth seven years after treatment was approximately 43 and 8 cm for the released and unreleased seedlings, respectively (Deen *et al.* 1993). In a Wisconsin study, removal of understory vegetation did not improve height growth or total height five years after treatment, with height growth averaging between 4 and 6 cm per year (Lorimer *et al.* 1994). Average total height of natural oak seedlings five years after treatment for the understory removal plots was 21 cm (Lorimer *et al.* 1994).

The lack of height growth response one year after understory vegetation control in the present study was partly due to the significantly lower pretreatment level of competing vegetation for the UVC treatment than the Control (SH15: 4.9 vs. 8.4, P = .0001) (Table 6). Had the level of competing vegetation on the UVC plots been similar to that of the Control plots, height growth response likely would have been greater. Low seedling vigor, as evidenced by flat-topped crowns, may also be a factor in the lack of response in height growth. While crown conformation was not recorded for the advance regeneration in the present study, the majority of stems observed had flat-topped crowns. Carvell (1967) determined that red and white oak seedlings with a flat crown conformation responded more slowly following release than seedlings with a distinct leader. Deen *et al.* (1993) also cited the flat-topped growth form as a contributing factor in the delay in height growth response following midstory and understory control on a high-quality bottomland hardwood site. In contrast to these findings, Loftis (1990b) found no correlation between degree of apical dominance prior to overstory removal and post-harvest performance of red oak advance regeneration on good to high-quality sites in North Carolina.

Measurement error, due to differing interpretations of the sampling protocol by the field crews, played a role in the lack of significant differences between the treatments. The straightening of the seedlings prior to measurement was the main source of error, and future measurements of height should be done without straightening the stem. It should be noted that shoot elongation was observed by the author to be approximately 2 to 3 cm or less for the majority of the seedlings, regardless of treatment. Moreover, the shoot elongation was typically in a near horizontal direction, and the growth would have been difficult to detect even if measurement error had not been a factor. Due to the relatively slow rate of height growth of understory oak seedlings, more time will be required to determine if understory vegetation control is effective in enhancing oak seedling growth.

An additional factor linked to a lack of early height growth is the tendency of some species to exhibit fixed growth, where the growth in any one year is preformed and, therefore, primarily determined by the previous year's weather and environmental conditions (Kozlowski et al. 1991). Under optimum conditions (light, water, and nutrients are not limiting) oak seedlings can make multiple growth flushes during one growing season (Richard Kreh 1996, pers. comm., Reynolds Homestead, Critz, Virginia). Because understory conditions, including low light and water availability, are likely not suitable to permit multiple flushes in a single growing season, understory oak seedlings likely exhibit fixed growth (Richard Kreh 1996, pers. comm., Reynolds Homestead, Critz, Virginia). Therefore no growth response due to increased resources would be expected until at least two years after treatment.

*Correlation Analyses*

The most significant variables relating to competition for light and water, as well the capacity for growth, were found to be pretreatment basal area per hectare ($BA_{1994}$), pre- and post-treatment percent crown cover ($CCOV_{1994 \text{ and } 1995}$), the pretreatment sum of the heights of competing stems (other than ericaceous vegetation) between 0 and 5 m tall ($SH05_{1994}$), the posttreatment sum of the heights of competing stems (other than ericaceous vegetation) greater than or equal to seedling height ($SHGSH_{1995}$), pretreatment height to diameter ratio (HDR), and pretreatment groundline diameter ($GLD_{1994}$) (Table 14). The degree of correlation for each of the above variables differed for each of the three species groups. Of the above variables, first year height growth was more strongly correlated to $CCOV_{1994}$ ($r = -.4665$, $P = .0001$), $HDR_{1994}$ ($r = -.2416$, $P = .0006$), and $GLD_{1994}$ ($r = .7847$, $P = .0001$) for the maple, red oak, and white oak group seedlings, respectively (Table 14).

The two variables $HDR_{1994}$ and $GLD_{1994}$ reflect the enhanced capacity for growth for seedlings with well-developed root systems. The relationship between groundline diameter and growth of oak advance regeneration was demonstrated by Loftis (1990b), where basal diameter was positively correlated to the postharvest probability of dominance for red oak advance regeneration. The negative relationship

**Table 14.** Correlation coefficients[1] and significance probabilities for first year seedling height growth (cm) and several related variables for maple red oak and white oak seedlings in mixed oak stands in southwest Virginia.

| Variable | Species Group | | |
|---|---|---|---|
| | Maple | Red Oak | White Oak |
| $HDR_{1994}$[2] (unitless) | -.1445<br>.0433 | -.2416<br>.0006 | -.1099<br>.1430 |
| $GLD_{1994}$[3] (cm) | -.0699<br>.3301 | .0857<br>.2264 | .7847<br>.0001 |
| $BA_{1994}$[4] ($m^2$/ha) | -.1348<br>.0597 | -.1078<br>.1279 | -.1990<br>.0076 |
| $CCOV_{1994}$[5] (%) | -.4665<br>.0001 | -.1207<br>.0880 | -.3907<br>.0001 |
| $CCOV_{1995}$[6] (%) | -.4438<br>.0001 | -.1047<br>.1393 | -.4160<br>.0001 |
| $SH05_{1994}$[7] (m) | -.2360<br>.0009 | -.2118<br>.0025 | -.1640<br>.0283 |
| $SHGSH_{1995}$[8] (m) | -.0432<br>.5480 | -.1473<br>.0369 | -.1877<br>.0119 |

[1] Pearson correlation coefficients (r) derived from PROC CORR (SAS Institute 1985); significance probabilities (PROB > |r|) are given below each correlation coefficient.

[2] Pretreatment height to diameter ratio of seedling ($HDR_{1994}$).
[3] Pretreatment groundline diameter ($GLD_{1994}$)

[4] Total basal area per acre ($ft^2\ ac^{-1}$) of stems > 5 m tall prior to treatment ($BA_{1994}$).

[5,6] Pre- and post-treatment percent crown cover as determined by spherical densiometer readings ($CCOV_{1994}$ and $CCOV_{1995}$, respectively).

[7] Sum of the pretreatment (1994) heights (m) of competing stems between 0 and 5m tall ($SH05_{1994}$).

[8] Posttreatment number of competing stems within a 1.5 meter radius of seedling greater than or equal to seedling height to 5 m tall($CSGSH_{1995}$).

between $GLD_{1994}$ and height growth for maple group seedlings in the present study was unexpected, but was likely due to the greater probability for measurement error of height for the larger maple seedlings caused by crown conformation. Often the maples had one main leader which did not grow vertically, but spread out horizontally. If the seedling was straightened inconsistently in each sampling period, the measurement error could be large and would be proportional to stem height. As stated in the previous section, future height measurements should be performed without straightening the seedlings, thereby eliminating that potential source of error.

While first year height growth showed a significant relationship with $CCOV_{1994}$ for the maple and white oak group seedlings ($r = -.4665$, $P = .0001$ and $r = -.3907$, $P = .0001$, respectively), the correlation was not as strong for red oak seedling height growth ($r = -.1207$, $P = .0880$) (Table 14). A similar trend was noted between $BA_{1994}$ and first year height growth (Table 14). Because maple and white oak group seedlings are generally more shade tolerant than red oak group seedlings (McQuilkin 1975), height growth would be expected to be more strongly related to light for the maple and white oak group seedlings. Shade tolerant seedlings should be better able to increase in height at lower light levels, or reach the light compensation point more rapidly, than shade intolerant seedlings, thereby having a stronger relationship between light and height growth, as long as the amount of available light is near the threshold level required for increased growth.

While the competition variable $SH05_{1994}$ was found to be significantly correlated to height growth for all three species groups, $SHGSH_{1995}$ was more closely correlated to first year height growth for the white oak group seedlings ($r = -.1877$, $P = .0119$ vs. $r = -.1640$, $P = .0283$). The correlation between $SH05_{1994}$ and height growth for the three species groups suggests that vegetation less than one meter tall can have a significant effect on seedling growth (Table 14). The relationship between white oak seedling height growth and $SHGSH_{1995}$ may indicate that overtopping vegetation is more important than subordinate competing vegetation, with regard to height growth.

**Groundline Diameter Growth**

No measurable groundline diameter growth was noted for either of the three species groups in the present study one year after treatment. Groundline diameter growth has been shown to be very slow in other studies involving understory vegetation removal. In a bottomland hardwood study in Mississippi, average root collar diameter growth over seven years was 0.31 and -0.15 cm for red oak seedlings in understory removal and control treatments, respectively (Deen et al. 1993). Average root collar diameter seven years after treatment was 0.76 and 0.44 cm for the understory removal and control seedlings, respectively (Deen et al. 1993). In a North Carolina study, in which a subcanopy treatment was performed, mean groundline diameter was 0.48 cm and 0.36 cm for the subcanopy treated and subcanopy untreated red oak seedlings nine years after treatment (Loftis 1990a). The red oak seedlings were established from seed at the time of treatment (Loftis 1990a). In the present study, pretreatment groundline diameter for maple, red oak and white oak seedlings was 1.23, 1.24, and 1.37 cm, respectively, across 2 treatments and 2 height classes. Differences in methodology in measuring diameter (root collar vs. groundline diameter) and differences in the age of seedlings being measured for the Mississippi and North Carolina studies, respectively, are likely the reasons behind the larger pretreatment groundline diameters reported in the present study than the posttreatment values reported in the above studies.

The lack of growth in groundline diameter in the present study, as well in other studies of this nature, is likely due in part to insufficient light needed for rapid growth. In the study by Loftis (1990a), a 20 percent reduction in overstory, from below, combined with the subcanopy treatment resulted in mean groundline diameter of 0.91 cm nine years after treatment compared with 0.48 cm for the subcanopy treatment alone. This suggests that overstory manipulation, in addition to a subcanopy treatment, may be necessary to realize noticeable differences in growth of groundline diameter.

Due to the taper of stems near groundline, measurement variability in the present study likely was a factor in the lack of measurable groundline diameter growth. Because of the slow growth increment of understory seedlings and the amount of taper near groundline, the measurement variability could exceed any growth that might occur.

**Effect of Understory Vegetation Control on Seedling Recruitment**

Understory vegetation control (UVC) did not enhance oak seedling recruitment, and the mean number of new oak seedlings declined for both treatments after one year (Table 15). Although the mast production was not measured in the present study, the decrease in the number of new seedlings across both treatments suggests that either the mast crop in the fall of 1994 was poor, or mast predation rates were high. While the results of the present study are preliminary, and inferences regarding the effectiveness of UVC in enhancing oak seedling recruitment cannot be made,

**Table 15.** Mean Density of new seedlings[1] for Understory Vegetation Control (UVC) and Control treatments prior to (Pre-tmt) and one year after (Post-tmt) treatment for mixed oak stands in southwest Virginia.

| Species | ---------Stems per Hectare---------- | | | |
|---|---|---|---|---|
| | UVC | | Control | |
| | Pre-tmt | Post-Tmt | Pre-tmt | Post-Tmt |
| Sassafras[2] | 3,036 | 15,041 | 2,183 | 1,628 |
| Downy Serviceberry | 3,289 | 12,658 | 247* | 0 |
| Red Maple | 5,946 | 3,909 | 6,404 | 1,204 |
| Scarlet Oak | 1,581 | 165 | 659 | 0 |
| Yellow-Poplar | 0 | 670 | 1,215 | 812 |
| White Oak | 2,151 | 329 | 247 | 0 |
| Cucumber Magnolia | 411 | 74 | 103 | 171 |
| Bear Oak | 0 | 0 | 618 | 0 |
| Chestnut Oak | 0 | 0 | 412 | 0 |
| Northern Red Oak | 601 | 0 | 0 | 0 |
| Black Oak | 285 | 0 | 947 | 0 |
| Fraser Magnolia | 0 | 0 | 0 | 171 |
| Black Gum | 0 | 0 | 700 | 171 |
| Striped Maple | 3,194 | 0 | 1,606 | 0 |
| Other species[3] | 11,134 | 4,383 | 12,913 | 2,533 |
| All oak species | 4,618 | 494 | 2,637 | 0 |
| All other species | 27,015 | 36,735 | 17,956 | 4,613* |
| **All species** | **31,628** | **37,229** | **20,593** | **4,613** |

[1] Includes only seedlings determined to be no greater than one year old.

[2] Scientific names are provided in Appendix C.

[3] Includes the following species: pignut hickory, mockernut hickory, beaked hazel, flowering dogwood, huckleberry, witch hazel, winterberry, mountain laurel, Virginia creeper, white pine, black cherry, azalea, *Rosa* spp., glaucous greenbrier, greenbrier, low blueberry, deerberry, mapleleaf viburnum, and *Vitis* spp.

* Values between treatments in same sampling period significantly different at $\alpha$ = .1 level (ANOVA, followed by Fisher's LSD). Statistical analyses performed on log transformed values.

oak seedling recruitment was improved by the reduction of midstory and understory vegetation in a bottomland hardwood study in Mississippi (Janzen and Hodges 1985). The Mississippi study showed that plots with midstory and understory vegetation control (Inject treatment) had significantly more new oak seedlings which germinated in the 3 years following treatment than plots in which no vegetation control was performed (15,026 vs. 6,027 stems $ha^{-1}$, respectively) (Janzen and Hodges 1985). This corresponds to an average of 5,009 and 2,009 stems $ha^{-1}$ germinating per year for the midstory/understory vegetation control and control plots, respectively, assuming equal germination between years. It should be noted that the presence of herbaceous vegetation partially explained the difference in the density of new seedlings between the two treatments. The plots that received midstory control had greater amounts of herbaceous vegetation, which trapped acorns during times of flooding and allowed for subsequent germination (Janzen and Hodges 1985). Other studies reporting oak seedling recruitment data following understory or midstory vegetation control could not be located. However, the total number of new oak seedlings present prior to treatment in the UVC and Control plots of the present study (4,618 and 2,883 stems $ha^{-1}$, respectively) are higher than the number of new seedlings germinating in the year after treatment reported by Sander (1972), which ranged from 712 to 2,740 stems $ha^{-1}$ for uncut and partially cut plots, respectively. In comparison, a West Virginia study reported 9,397 and 3,264 stems $ha^{-1}$ of new oak germinants (all oak species) on plots that were considered to have 'good' and 'poor' oak regeneration, respectively (Tryon and Carvell 1958).

Many factors affect the number of new seedlings that become established in a given year. These factors include seed production, dissemination, and predation; germinative capacity; and weather (McQuilkin 1983). Even after a 'good' seed year the number of oak seedlings becoming established may range from none to thousands per hectare, depending upon predation rates, and overwintering and germination conditions (McQuilkin 1983). Therefore, the decrease in the number of new oak seedlings established in the present study is not uncommon and several years will be required to determine if the treatment is successful in improving oak advance regeneration recruitment. Perhaps a good measure of treatment effectiveness in future analyses would be the ratio of the number of new oak seedlings surviving over a given time period to the sum of new seedlings germinating in the same time.

The number of new sassafras and downy serviceberry seedlings increased for the UVC treatment after one year

(3,036 to 15,041 stems $ha^{-1}$ and 3,289 to 12,658 stems $ha^{-1}$, respectively). In contrast, the density of new sassafras and downy serviceberry seedlings declined for the Control treatment (2,183 to 1,628 stems $ha^{-1}$ and 247 to 0 stems $ha^{-1}$, respectively), while the posttreatment differences were not significant at the $\alpha = .1$ level (Table 15). The majority of the downy serviceberry seedlings observed were less than 2 cm tall and are not expected to survive. The sassafras seedlings were of root-sprout origin, but were termed new seedlings because the shoots were obviously less than one year old. While the variance in density of the sassafras and downy serviceberry seedlings precluded any posttreatment significant differences, total non-oak species density was significantly less for the Control plots than for the UVC plots (4,613 vs. 36,735 stems $ha^{-1}$, $P < .1$) one year after treatment (Table 15). More time will be required to determine if the treatment favors the recruitment of other species relative to oaks. The data show that the number of new seedlings established for any particular species may vary greatly from one year to the next (Table 15).

## Effect of Understory Vegetation Control on Relative Species Abundance

Total density of seedlings 0 to 1 meter tall increased for both the UVC and Control treatments after one year

(120,914 to 130,632 stems $ha^{-1}$ and 139,197 to 153,034 stems $ha^{-1}$, respectively), although the change in relative abundance was not great for any particular species (Table 16). The increase in total density was likely due to the survival of new germinants from the pretreatment data collection period or due to an influx of stems with top dieback. The fluctuation in the density of small seedlings from one year to the next is quite common. According to Loftis (1990a) the number of seedlings less than 30.4 cm (1 ft) is transient and can vary greatly from year to year. The transient nature of the small stems noted by Loftis (1990a) is likely due to the survival (or mortality) of newly germinated seedlings, which has been shown to vary greatly from year to year.

The relative proportion of oak seedlings (all species) 0 to 1 m tall did increase slightly for the UVC plots (14.6 to 16.3 percent), whereas the proportion of oaks in the Control plots remained about the same (11.5 to 11.3 percent) after one year (Table 16). If the UVC treatment can increase the size of oak seedlings in the 0 to 1 m height class over time, given the significant number of oak seedlings 0 to 1 m tall, then the treatment can be considered effective. It should be noted, though, that the treatment response of the competing species in the same height class is also of considerable importance when evaluating the effectiveness of

**Table 16.** Relative density of seedlings (greater than one year old) 0 to 1 meter tall for Understory Vegetation Control (UVC) and Control treatments prior to (Pre-tmt) and one year after treatment (Post-tmt) for mixed oak stands in southwest Virginia.

| Species | Density % | | | |
|---|---|---|---|---|
| | UVC | | Control | |
| | Pre-tmt | Post-Tmt | Pre-tmt | Post-Tmt |
| Low Blueberry[2] | 17.2[3] | 17.0 | 18.8 | 18.4 |
| Sassafras | 6.6 | 8.4 | 4.7 | 5.2 |
| Downy Serviceberry | 7.2 | 6.7 | 2.2 | 1.6 |
| Red Maple | 6.8 | 6.8 | 14.1 | 16.1 |
| Azalea spp. | 7.4 | 5.5 | 7.6 | 8.4 |
| Northern Red Oak | 4.0 | 4.5 | 0.7 | 1.2 |
| White Oak | 4.3 | 3.9 | 4.3 | 4.3 |
| Scarlet Oak | 2.9 | 3.8 | 2.7 | 1.8 |
| Striped Maple | 1.7 | 3.6 | 3.4 | 3.6 |
| Deerberry | 3.1 | 3.0 | 7.3 | 8.2 |
| Cucumber Magnolia | 3.3 | 2.9 | 7.8 | 4.1 |
| Beaked Hazel | 1.8 | 2.9 | 4.1 | 3.9 |
| Chestnut Oak | 1.9 | 2.5 | 0.8 | 1.4 |
| Huckleberry | 3.6 | 1.6 | 1.8 | 1.5 |
| Bear Oak | 0.4 | 1.1 | 1.3 | 1.5 |
| Black Gum | 0.8 | 0.9 | 0.8 | 3.9 |
| Highbush Blueberry | 0.4 | 0.8 | 0.7 | 0.9 |
| Black Oak | 1.1 | 0.5 | 1.7 | 1.1 |
| Fraser Magnolia | 0.4 | 0.2 | 0.2 | 0.5 |
| White Ash | 0.0 | 0.4 | 0.2 | 0.1 |
| Mockernut Hickory | 0.4 | 0.3 | 0.4 | 0.3 |
| Pignut Hickory | 0.3 | 0.3 | 0.1 | 0.1 |
| Green Ash | 0.0 | 0.2 | 0.0 | 0.2 |
| Other species[3] | 24.4 | 22.2 | 14.3 | 11.7 |
| All oak species (%) | 14.6 | 16.3 | 11.5 | 11.3 |
| | Stems per Hectare | | | |
| **All species** | **120,914** | **130,632** | **139,197** | **153,034** |

[1] Scientific names are provided in Appendix C.

[2] Differences between treatments not significant at $\alpha$ = .1 level (ANOVA, followed by Fisher's LSD).

[3] Includes the following species: American chestnut, Allegheny chinkapin, flowering dogwood, hawthorne, witch hazel, mountain laurel, yellow-poplar, Virginia creeper, Virginia pine, black cherry, winged sumac, black locust, Rosa spp., *Rubus* spp., glaucous greenbrier, greenbrier, poison ivy, mapleleaf viburnum, and *Vitis* spp.

the UVC treatment.

The total density of non-oak species 1 to 2 m and 2 to 5 m tall was reduced by the UVC treatment after one year (1,406 to 477 stems $ha^{-1}$ and 1,011 to 440 stems $ha^{-1}$, respectively), although the total density of non-oak species in the Control plots decreased as well (2,903 to 1,967 stems $ha^{-1}$ and 1,581 to 1,433 stems $ha^{-1}$, respectively) (Tables 17 and 18). The decrease in the total density of seedlings 1 to 2 m and 2 to 5 m tall for the Control plots may have been due to factors such as the occurrence of top dieback, growth (into a new height class), or mortality. The UVC treatment did not increase the relative proportion of oak species 1 to 2 m tall, which decreased from 5.6 to 3.7 percent, and total oak density decreased after one year (Table 17). The decrease in total oak density can be partially explained by the growth of stems into the 2 to 5 m height class. Certain species between 2 and 5 m tall, such as chestnut oak and scarlet oak, did increase in density, and showed a corresponding decrease in density of seedlings 1 to 2 m tall (Tables 17 and 18). While sampling error was likely not a significant factor, seedlings could have been incorrectly placed in a height class due to inaccurate height measurement and could account for a change in density for any particular strata.

The relative density of oak seedlings 2 to 5 m tall was

**Table 17.** Relative density of seedlings 1 to 2 meters tall for Understory Vegetation Control (UVC) and Control treatments prior to (Pre-tmt) and one year after treatment (Post-tmt) for mixed oak stands in southwest Virginia.

| Species | Density % | | | |
|---|---|---|---|---|
| | UVC | | Control | |
| | Pre-tmt | Post-Tmt | Pre-tmt | Post-Tmt |
| Highbush Blueberry[1] | 14.8 | 23.3 | 3.2 | 1.2 |
| Black Gum | 11.0 | 20.6 | 7.2 | 4.7 |
| Red Maple | 2.2 | 13.2 | 15.0* | 15.4 |
| Downy Serviceberry | 15.4 | 8.0 | 6.4 | 9.5 |
| Sassafras | 3.9 | 4.8 | 3.3 | 4.0 |
| Striped Maple | 3.7 | 3.3 | 4.0 | 5.7 |
| Mockernut Hickory | 3.2 | 3.7 | 4.0 | 3.8 |
| Pignut Hickory | 3.2 | 3.7 | 0.0 | 0.7 |
| Flowering Dogwood | 5.5 | 3.7 | 5.2 | 4.0 |
| White Oak | 1.6 | 3.7 | 1.2 | 1.5 |
| Scarlet Oak | 2.8 | 0.0 | 6.0 | 5.8 |
| Yellow-Poplar | 0.0 | 0.0 | 0.6 | 1.0 |
| Cucumber Magnolia | 1.2 | 0.0 | 9.5 | 9.2 |
| Black Oak | 0.0 | 0.0 | 3.6 | 2.8 |
| Bear Oak | 0.0 | 0.0 | 1.6 | 1.5 |
| Fraser Magnolia | 0.0 | 0.0 | 0.0 | 1.1 |
| Northern Red Oak | 0.0 | 0.0 | 0.6 | 1.0 |
| Chestnut Oak | 1.2 | 0.0 | 1.8 | 0.7 |
| Witch Hazel | 3.6 | 0.0 | 0.5 | 0.0 |
| Other species[2] | 26.7 | 12.0 | 26.3 | 26.4 |
| All oak species (%) | 5.6 | 3.7 | 14.8 | 13.3 |
| | Stems per Hectare | | | |
| **All species** | **1406** | **477** | **2903*** | **1967*** |

[1] Scientific names are provided in Appendix C.

[2] Includes the following species: black birch, American chestnut, beaked hazel, hawthorne, American beech, white ash, huckleberry, mountain laurel, sourwood, white pine, Virginia pine, azalea, *Rubus* spp., glaucous greenbrier, greenbrier, deerberry, and mapleleaf viburnum.

* Values within species and date of measurement followed by same letter not significantly different at $\alpha$ = .1 level (ANOVA, followed by Fisher's LSD). Statistical analysis performed on square root transformed percentages.

**Table 18.** Relative density of seedlings 2 to 5 meters tall for Understory Vegetation Control (UVC) and Control treatments prior to (Pre-tmt) and one year after treatment (Post-tmt) for mixed oak stands in southwest Virginia.

| Species | Density % | | | |
|---|---|---|---|---|
| | UVC | | Control | |
| | Pre-tmt | Post-Tmt | Pre-tmt | Post-Tmt |
| Mountain Winterberry[1] | 5.2[2] | 24.2 | 0.0 | 0.0 |
| White Oak | 5.3 | 11.4 | 0.0 | 1.1 |
| Black Gum | 12.8 | 10.2 | 10.9 | 16.5 |
| Mockernut Hickory | 7.5 | 10.2 | 7.6 | 4.4 |
| Pignut Hickory | 0.0 | 8.3 | 2.2 | 2.6 |
| Sourwood | 5.5 | 6.7 | 3.6 | 1.9 |
| Highbush Blueberry | 1.9 | 6.7 | 0.0 | 0.0 |
| Chestnut Oak | 0.0 | 3.0 | 2.2 | 1.1 |
| Flowering Dogwood | 7.5 | 3.0 | 12.4 | 10.3 |
| Scarlet Oak | 2.2 | 3.0 | 0.0 | 3.3 |
| Downy Serviceberry | 13.0 | 0.0 | 6.3 | 13.3 |
| Red Maple | 9.0 | 0.0 | 13.1 | 8.3 |
| Fraser Magnolia | 1.8 | 0.0 | 7.2 | 8.6 |
| Black Oak | 0.0 | 0.0 | 3.6 | 5.9 |
| Cucumber Magnolia | 0.0 | 0.0 | 6.5 | 5.7 |
| Northern Red Oak | 0.0 | 0.0 | 4.0 | 3.3 |
| Striped Maple | 1.8 | 0.0 | 1.4 | 1.9 |
| Witch Hazel | 10.8 | 0.0 | 1.4 | 1.9 |
| White Ash | 0.0 | 0.0 | 1.3 | 1.1 |
| Post Oak | 0.0 | 0.0 | 2.2 | 0.0 |
| Other species[3] | 15.7 | 13.3 | 14.1 | 8.8 |
| All oak species (%) | 7.5 | 17.4 | 12.2 | 14.7 |
| | Stems per Hectare | | | |
| **All species** | **1011** | **440** | **1581** | **1433** |

[1] Scientific names are provided in Appendix C.

[2] Differences between treatments not significant at $\alpha = .1$ level (ANOVA, followed by Fisher's LSD). Statistical analysis performed on square root transformed percentages.

[3] Includes the following species: American chestnut, hawthorne, white pine, Virginia pine, greenbrier, and *Vitis* spp.

increased by the UVC treatment (from 7.5 to 17.4 percent), and the majority of the shade tolerant species 2 to 5 m tall were eliminated, which should give the oaks a competitive advantage after a future harvest cut. More time is required to determine if the UVC treatment is effective in increasing the density of large oak advance regeneration. In addition, the potential effects of such a treatment on the development of other species is, at this point, unclear. Other studies involving understory and midstory vegetation removal have not reported the changes in density of species other than oak over time. Therefore, there is no basis for comparison regarding the results of the present study.

The greater relative density of species such as blackgum, flowering dogwood, downy serviceberry, mountain winterberry, and red maple in the 1 to 2 m and 2 to 5 m height classes reflects their greater shade tolerance as compared to more intolerant species such as yellow-poplar, as well as oak and hickory species (Tables 17 and 18). The general trend in the density data shows the shade tolerant species are represented in increasing proportions with increasing height class levels (Tables 17 and 18). Future measurements, including post-harvest measurements, are required to determine if the treatment of this tolerant subcanopy is necessary for oak regeneration to be successful. For the present study, remeasurement would be appropriate at 3, 5, and 7 years after treatment, which should allow adequate time for a treatment response to occur.

## SUMMARY and IMPLICATIONS

While the understory vegetation control (UVC) treatment significantly reduced the sum of the heights of competing stems (1 to 5 m tall) within 1.5 meters of tagged seedlings, neither oak seedling height growth nor oak seedling recruitment was improved by the UVC treatment after one year. Insufficient time has elapsed for a treatment response to become evident.

First year seedling height growth was found to be most strongly correlated with pretreatment overhead crown cover ($CCOV_{1994}$), pretreatment height to diameter ratio ($HDR_{1994}$), and pretreatment groundline diameter ($GLD_{1994}$) for the maple, red oak, and white oak group seedlings, respectively. Variables such as $HDR_{1994}$ and $GLD_{1994}$ should prove to be significant predictors of seedling height growth in future analyses, as they are indicative of seedling root development.

Seedling mortality for maple, red oak, and white oak group seedlings was found to be more closely related to pretreatment seedling height rather than treatment, with seedings 0 to 1 m tall exhibiting higher mortality than 1 to 2 m seedlings. The percent of seedlings with either partial top dieback or complete top dieback (with resprout) showed no consistent trend with regard to species or treatment and ranged between 1.4 and 8.2 percent.

The UVC treatment reduced the density of non-oak species 1 to 2 m and 2 to 5 m tall and increased the relative proportion of oak species 2 to 5 m tall one year after treatment. The relative proportion of oak species 1 to 2 m tall decreased after one year, however. The UVC treatment can be considered effective in eliminating competing vegetation, although the basal application of triclopyr in a methyl oleate carrier showed a lack of efficacy in controlling blackgum, flowering dogwood, and *Magnolia* spp. The hack and squirt method may be necessary for successful control of such species.

The results of the present study are preliminary and no conclusions regarding the effectiveness of the UVC treatment in improving the competitive status or recruitment of oak species can be drawn at this time. Based on the results of similar research, as much as 3 to 5 years, or more, may be required for the treatment response to become evident. In addition, the removal or control of some percentage of stems in the intermediate crown class and above (in combination with UVC) may be necessary for seedling growth to be greatly enhanced as indicated by Loftis (1990a). Nonetheless, the reduction of competing understory vegetation should improve the competitive status of oak seedlings, with or without the removal of upper canopy class trees.

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# APPENDIX A

**Preferred Species List**

| Scientific Name | Common Name | Species Code |
|---|---|---|
| **Prunus serotina**[1] | black cherry | PRSE |
| **Quercus rubra** | northern red oak | QURU |
| **Carya glabra** | pignut hickory | CAGL |
| **Carya tomentosa** | mockernut hickory | CATO |
| **Quercus alba** | white oak | QUAL |
| **Acer saccharum** | sugar maple | ACSA |
| **Quercus velutina** | black oak | QUVE |
| **Fraxinus americana** | white ash | FRAM |
| **Fraxinus pennsylvanica** | green ash | FRPE |
| **Quercus prinus** | chestnut oak | QUPR |
| **Quercus coccinea** | scarlet oak | QUCO |
| **Fagus grandifolia** | American beech | FAGR |
| **Pinus strobus** | white pine | PIST |
| **Liriodendron tulipifera** | yellow poplar | LITU |
| Acer rubrum | red maple | ACRU |
| Sassafras albidum | sassafras | SAAL |
| Tsuga canadensis | eastern hemlock | TSCA |
| Pinus rigida | pitch pine | PIRI |
| Cornus florida | flowering dogwood | COFL |
| Betula lenta | black birch | BELE |
| Magnolia acuminata | cucumber magnolia | MAAC |
| Pinus virginiana | Virginia pine | PIVI |
| Nyssa sylvatica | blackgum | NYSY |
| Acer pennsylvanicum | striped maple | ACPE |
| Robinia pseudoacacia | black locust | ROPS |

[1] Species are listed in declining order, with respect to preference, and the 14 most preferred species are listed in bold. See the following two pages for an explanation of the development process for the above preferred species list.

**Selection of the Preferred Species**

The preferred species list was generated by assigning each species a 1 to 5 numerical value for each of the following criteria: Lumber Value, Wildlife Value, Longevity, and Gypsy Moth Susceptibility (Table A-1). Each criteria was weighted by multiplying the assigned, 1 to 5, value by 0.3, 0.3, 0.15, and 0.25, respectively (Table A-1). The weighted values are then summed and the species with the highest total value is the most preferred species[1]. In this manner the preferred species were chosen based on multiple criteria, and not solely on lumber value.

The values were assigned to each species by determining the relative value of each species for the criteria listed above. The lumber values were chosen based on prices for FAS lumber as reported in the June 1993 Hardwood Market Report. The values assigned to each species for the Wildlife and Longevity criteria were determined by information given Burns and Honkala (1990).in Agricultural Handbook 654, Volumes 1 and 2, Silvics of North America. The Gypsy Moth Susceptibility values were determined by ratings given in USDA FOR. SERV. GEN. TECH. REP. NE-171, Silvicultural Guidelines for Forest Stands Threatened by the Gypsy Moth, by Kurt W. Gottschalk.

[1] Species which are highly susceptible to gypsy moth damage received **low** values.

**Table A-1.** Weighted values[1] for Lumber Value, Wildlife Value, Longevity, and Gypsy Moth Susceptibility for species common to southwest Virginia.

| Species Code | Lumber Value | Wildlife Value | Longevity | Gypsy Moth | Total |
|---|---|---|---|---|---|
| PRSE | 1.5 | 1.5 | .48 | .5 | 3.98 |
| QURU | 1.5 | 1.5 | .6 | .25 | 3.85 |
| CAGL | .9 | 1.5 | .6 | .5 | 3.5 |
| CATO | .9 | 1.5 | .6 | .5 | 3.5 |
| QUAL | 1.29 | 1.2 | .75 | .25 | 3.49 |
| ACSA | 1.2 | .9 | .75 | .5 | 3.35 |
| QUVE | 1.2 | 1.35 | .495 | .25 | 3.295 |
| FRAM | 1.26 | .75 | .525 | .75 | 3.295 |
| FRPE | 1.26 | .75 | .525 | .75 | 3.285 |
| QUPR | 1.05 | 1.35 | .6 | .25 | 3.25 |
| QUCO | 1.2 | 1.2 | .48 | .25 | 3.13 |
| FAGR | .75 | 1.2 | .675 | .5 | 3.125 |
| PIST | 1.05 | .75 | .525 | .75 | 3.075 |
| LITU | 1.08 | .6 | .525 | .75 | 2.955 |
| ACRU | 1.05 | .9 | .45 | .5 | 2.9 |
| SAAL | .6 | 1.2 | .525 | .5 | 2.825 |
| TSCA | .6 | .9 | .75 | .5 | 2.75 |
| PIRI | .78 | .75 | .45 | .75 | 2.73 |
| COFL | 0.0 | 1.5 | .45 | .75 | 2.7 |
| BELE | .96 | .6 | .525 | .5 | 2.585 |
| MAAC | .99 | .6 | .45 | .5 | 2.54 |
| PIVI | .6 | .75 | .375 | .75 | 2.475 |
| NYSY | .6 | .9 | .45 | .5 | 2.45 |
| ACPE | .3 | .9 | .3 | .5 | 2.0 |
| ROPS | .3 | .6 | .3 | .75 | 1.95 |

[1] The original (unweighted) species values ranged from 1 to 5 and were weighted by 0.3, 0.3, 0.15, and 0.25 for the Lumber Value, Wildlife Value, Longevity, and Gypsy Moth Susceptibility criteria, respectively. Larger total numbers indicate a more preferred species.

# APPENDIX B

**Table B-1.** Pretreatment overstory relative density and relative basal area by diameter class at the Fishburn Site - Control Plot.

| Species | -----Density %----- | | | ---Basal Area %--- | | |
|---|---|---|---|---|---|---|
| | <25cm | >25cm | Total | <25cm | >25cm | Total |
| White Oak | 15.6 | 1.7 | 17.3 | 13.4 | 11.2 | 24.6 |
| Scarlet Oak | 13.9 | 2.9 | 16.8 | 13.7 | 18.3 | 32.0 |
| Black Oak | 10.9 | -- | 10.9 | 13.3 | -- | 13.3 |
| Virginia Pine | 9.2 | 0.6 | 9.8 | 8.0 | 3.2 | 11.2 |
| Pignut Hickory | 5.8 | -- | 5.8 | 1.6 | -- | 1.6 |
| Chestnut Oak | 6.4 | 0.6 | 7.0 | 4.9 | 3.2 | 8.1 |
| Mockernut Hickory | 6.9 | -- | 6.9 | 2.0 | -- | 2.0 |
| Downy Serviceberry | 6.9 | -- | 6.9 | 1.6 | -- | 1.6 |
| Post Oak | 6.4 | -- | 6.4 | 1.7 | -- | 1.7 |
| Black Gum | 5.2 | -- | 5.2 | 1.1 | -- | 1.1 |
| Red Maple | 4.0 | -- | 4.0 | 0.7 | -- | 0.7 |
| Sassafras | 1.7 | -- | 1.7 | 0.2 | -- | 0.2 |
| Southern Red Oak | 0.6 | -- | 0.6 | 0.4 | -- | 0.4 |
| White Pine | 0.6 | -- | 0.6 | 1.3 | -- | 1.3 |
| Total | 94.1 | 5.8 | 99.9 | 63.9 | 35.9 | 99.8 |
| | stems per hectare | | | $m^2$ per hectare | | |
| All species | 943 | 58 | 1001 | 10.6 | 5.9 | 16.5 |

**Table B-2.** Pretreatment overstory relative density and relative basal area by diameter class at the Fishburn Site - Understory Vegetation Control Plot.

| Species | ----Density %---- | | | ---Basal Area %--- | | |
|---|---|---|---|---|---|---|
| | <25cm | >25cm | Total | <25cm | >25cm | Total |
| White Oak | 22.9 | 6.2 | 29.1 | 8.8 | 18.2 | 27.0 |
| Chestnut Oak | 20.8 | 3.1 | 23.9 | 14.8 | 5.7 | 20.5 |
| Scarlet Oak | 6.2 | 8.3 | 14.5 | 5.8 | 24.0 | 29.8 |
| Mockernut Hickory | 13.5 | -- | 13.5 | 5.2 | -- | 5.2 |
| Black Oak | 6.2 | 1.0 | 7.2 | 6.4 | 5.1 | 11.5 |
| Pignut Hickory | 3.1 | 1.0 | 4.1 | 1.3 | 1.7 | 3.0 |
| White Pine | 2.1 | -- | 2.1 | 2.1 | -- | 2.1 |
| Post Oak | 1.0 | -- | 1.0 | 0.8 | -- | 0.8 |
| Downy Serviceberry | 1.0 | -- | 1.0 | 0.1 | -- | 0.1 |
| Black Cherry | 1.0 | -- | 1.0 | 0.0 | -- | 0.0 |
| Sugar Maple | 1.0 | -- | 1.0 | 0.0 | -- | 0.0 |
| White Ash | 1.0 | -- | 1.0 | 0.0 | -- | 0.0 |
| Total | 79.8 | 19.6 | 99.4 | 45.3 | 54.7 | 100 |
| | stems per hectare | | | $m^2$ per hectare | | |
| All species | 446 | 110 | 556 | 8.4 | 10.2 | 18.6 |

**Table B-3.** Pretreatment overstory relative density and relative basal area by diameter class at the Blacksburg Site - Control Plot.

| Species | Density % | | | Basal Area % | | |
|---|---|---|---|---|---|---|
| | <25cm | >25cm | Total | <25cm | >25cm | Total |
| Red Maple | 21.7 | -- | 21.7 | 2.0 | -- | 2.0 |
| White Oak | 11.7 | 8.5 | 20.2 | 15.2 | 31.6 | 46.8 |
| Chestnut Oak | 8.5 | 6.1 | 14.6 | 5.9 | 20.6 | 26.5 |
| Mockernut Hickory | 13.2 | -- | 13.2 | 3.3 | -- | 3.3 |
| Black Oak | 2.3 | 2.3 | 4.6 | 2.1 | 8.8 | 10.9 |
| Yellow-Poplar | 5.4 | -- | 5.4 | 0.4 | -- | 0.4 |
| Black Gum | 3.9 | -- | 3.9 | 0.3 | -- | 0.3 |
| Sugar Maple | 3.9 | -- | 3.9 | 0.4 | -- | 0.4 |
| Flowering Dogwood | 3.1 | -- | 3.1 | 0.3 | -- | 0.3 |
| Downy Serviceberry | 2.3 | -- | 2.3 | 0.2 | -- | 0.2 |
| White Ash | 2.3 | -- | 2.3 | 0.2 | -- | 0.2 |
| Scarlet Oak | 0.8 | 1.6 | 2.4 | 1.4 | 4.5 | 5.9 |
| American Chestnut | 0.8 | -- | 0.8 | 0.0 | -- | 0.0 |
| Pignut Hickory | 0.8 | -- | 0.8 | 0.0 | -- | 0.0 |
| Pitch Pine | -- | 0.8 | 0.8 | -- | 2.6 | 2.6 |
| Total | 80.7 | 19.3 | 100 | 31.7 | 58.1 | 99.8 |
| | stems per hectare | | | $m^2$ per hectare | | |
| All species | 602 | 145 | 747 | 6.6 | 14.1 | 20.7 |

**Table B-4.** Pretreatment overstory relative density and relative basal area by diameter class at the Blacksburg Site - Understory Vegetation Control Plot.

| Species | ----Density %---- | | | ---Basal Area %--- | | |
|---|---|---|---|---|---|---|
| | ≤25cm | ≥25cm | Total | ≤25cm | ≥25cm | Total |
| White Oak | 14.9 | 7.0 | 21.9 | 11.6 | 23.9 | 35.5 |
| Chestnut Oak | 16.1 | 2.3 | 18.4 | 9.9 | 8.2 | 18.1 |
| Red Maple | 14.4 | -- | 14.4 | 3.2 | -- | 3.2 |
| White Pine | 14.4 | 1.1 | 15.5 | 9.1 | 2.1 | 11.2 |
| Mockernut Hickory | 6.9 | -- | 6.9 | 1.3 | -- | 1.3 |
| Flowering Dogwood | 1.1 | -- | 1.1 | 0.5 | -- | 0.5 |
| Black Gum | 6.3 | -- | 6.3 | 0.5 | -- | 0.5 |
| Scarlet Oak | 2.9 | 5.2 | 8.1 | 2.5 | 15.8 | 18.3 |
| Pitch Pine | 1.1 | 2.3 | 3.4 | 1.7 | 9.0 | 10.7 |
| Downy Serviceberry | 0.3 | -- | 0.3 | 0.3 | -- | 0.3 |
| Black Locust | 1.1 | -- | 1.1 | 0.3 | -- | 0.3 |
| Striped Maple | 0.6 | -- | 0.6 | 0.1 | -- | 0.1 |
| Total | 80.1 | 17.9 | 98 | 41 | 59 | 100 |
| | stems per hectare | | | $m^2$ per hectare | | |
| All species | 828 | 179 | 1007 | 12.6 | 18.1 | 30.7 |

**Table B-5.** Pretreatment overstory relative density and relative basal area by diameter class at the Clinch Site - Control Plot.

| Species | Density % | | | Basal Area % | | |
|---|---|---|---|---|---|---|
| | ≤25cm | >25cm | Total | ≤25cm | >25cm | Total |
| Red Maple | 23.7 | 0.7 | 24.4 | 6.9 | 1.7 | 8.6 |
| Northern Red Oak | 8.8 | 7.1 | 15.9 | 7.2 | 17.6 | 24.8 |
| Fraser Magnolia | 13.6 | 0.7 | 14.3 | 3.6 | 1.7 | 5.3 |
| Sourwood | 7.1 | 2.4 | 9.5 | 4.2 | 4.6 | 8.8 |
| Black Gum | 2.4 | 5.4 | 7.8 | 1.7 | 20.3 | 22.0 |
| Downy Serviceberry | 7.1 | -- | 7.1 | 2.2 | -- | 2.2 |
| Chestnut Oak | 4.1 | 2.4 | 6.5 | 4.4 | 6.5 | 10.9 |
| Striped Maple | 4.1 | -- | 4.1 | 1.0 | -- | 1.0 |
| Black Oak | 0.7 | 2.4 | 3.1 | 0.6 | 6.5 | 7.1 |
| American Chestnut | 3.1 | -- | 3.1 | 0.2 | -- | 0.2 |
| Flowering Dogwood | 0.7 | -- | 0.7 | 0.1 | -- | 0.1 |
| Mountain Winterberry | 0.7 | -- | 0.7 | 0.1 | -- | 0.1 |
| Cucumber Magnolia | 0.7 | -- | 0.7 | 0.3 | -- | 0.3 |
| White Oak | -- | 1.7 | 1.7 | -- | 8.6 | 8.6 |
| Total | 76.8 | 22.8 | 99.6 | 32.5 | 67.5 | 100 |
| | stems per hectare | | | $m^2$ per hectare | | |
| All species | 563 | 166 | 729 | 9.2 | 19.2 | 28.4 |

**Table B-6.** Pretreatment overstory relative density and relative basal area by diameter class at the Clinch Site - Understory Vegetation Control Plot.

| Species | -----Density %---- | | | ---Basal Area %--- | | |
|---|---|---|---|---|---|---|
| | ≤25cm | ≥25cm | Total | ≤25cm | ≥25cm | Total |
| Red Maple | 30.0 | 4.5 | 34.5 | 9.0 | 8.4 | 17.4 |
| Downy Serviceberry | 20.1 | -- | 20.1 | 4.2 | -- | 4.2 |
| Northern Red Oak | 7.3 | 6.1 | 13.4 | 7.8 | 22.8 | 30.6 |
| White Oak | 2.9 | 3.8 | 6.7 | 2.2 | 14.4 | 16.6 |
| Sourwood | 3.8 | 2.2 | 6.0 | 2.4 | 4.2 | 6.6 |
| Chestnut Oak | 2.9 | 2.8 | 5.7 | 2.4 | 8.4 | 10.8 |
| Striped Maple | 3.8 | -- | 3.8 | 1.0 | -- | 1.0 |
| Black Birch | 2.2 | 0.6 | 2.8 | 0.2 | 4.2 | 4.4 |
| Witch Hazel | 2.9 | -- | 2.9 | 0.2 | -- | 0.2 |
| Cucumber Magnolia | -- | 0.6 | 0.6 | -- | 1.9 | 1.9 |
| Fraser Magnolia | 0.6 | -- | 0.6 | 0.2 | -- | 0.2 |
| Black Gum | -- | 0.6 | 0.6 | -- | 3.6 | 3.6 |
| Total | 76.5 | 21.2 | 97.7 | 29.6 | 67.9 | 97.5 |
| | stems per hectare | | | $m^2$ per hectare | | |
| All species | 610 | 166 | 776 | 9.8 | 20.5 | 30.3 |

**APPENDIX C**

Scientific and common names for species located.

| Common Name | Scientific Name |
|---|---|
| Allegheny chinkapin | *Castanea pumila* (L.) Mill. |
| American beech | *Fagus grandifolia* Ehrh. |
| American chestnut | *Castanea dentata* (Marsh.) Borkh. |
| Azalea spp. | *Rhododendron* spp. L. |
| Beaked hazel | *Corylus cornuta* Marsh. |
| Bear oak | *Quercus illicifolia* Wang. |
| Black birch | *Betula lenta* L. |
| Black cherry | *Prunus serotina* Ehrh. |
| Blackgum | *Nyssa sylvatica* L. |
| Blackhaw viburnum | *Viburnum prunifolium* L. |
| Black oak | *Quercus velutina* Lam. |
| Chestnut oak | *Quercus prinus* L. |
| Cucumber magnolia | *Magnolia acuminata* L. |
| Deerberry | *Vaccinium staminium* L. |
| Downy serviceberry | Amelanchier arborea |
| Flowering dogwood | *Cornus florida* L. |
| Fraser Magnolia | *Magnolia fraseri* Walt. |
| Glaucous greenbrier | *Smilax glauca* Walt. |
| Greenbrier | *Smilax rotundifolia* L. |
| Hawthorn | *Crataegus* spp. L. |
| Highbush blueberry | *Vaccinium corymbosum* L. |
| Huckleberry | Gaylussacia baccata (Wang.) K. Koch. |
| Low blueberry | *Vaccinium vacillans* Torr. |
| Mockernut hickory | *Carya tomentosa* Nutt. |
| Mountain laurel | *Kalmia latifolia* L. |
| Mountain winterberry | *Ilex verticillata* (L.) Gray. |
| Multiflora rose | *Rosa multiflora* Thunb. |
| Northern red oak | *Quercus rubra* L. |
| Pignut hickory | *Carya glabra* (Mill.) Sweet. |
| Post oak | *Quercus stellata* Wang. |
| Red maple | *Acer rubrum* L. |
| Rubus spp. | *Rubus* spp. L. |
| Sassafras | *Sassafras albidum* (Nutt.) Nees. |
| Scarlet oak | *Quercus coccinea* Muenchh. |
| Sourwood | *Oxydendrum arboreum* (L.) DC. |
| Striped maple | *Acer pensylvanicum* L. |
| Virginia creeper | *Parthenocissus quinquefolia* Plank. |
| Virginia pine | *Pinus virginiana* Mill. |
| White ash | *Fraxinus americana* L. |
| White oak | *Quercus alba* L. |
| White pine | *Pinus strobus* L. |
| Wild grape | *Vitis* spp. L. |
| Witch hazel | *Hamamelis virginiana* L. |
| Yellow-poplar | *Liriodendron tulipifera* L. |

**APPENDIX D**

**Table D-1.** Pretreatment species density of stems between 2 and 5 meters in height found on the Blacksburg, Fishburn, and Clinch Sites for the Control and Understory Vegetation Control Treatment Plots.

| | **Control Plot** | | |
|---|---|---|---|
| | <-------stems per hectare-------> | | |
| Species | Blacksburg | Fishburn | Clinch |
| Red maple | 385 | -- | 385 |
| Flowering dogwood | 331 | 111 | -- |
| Mockernut hickory | 220 | 54 | -- |
| Blackgum | 166 | 220 | 54 |
| Northern red oak | 166 | -- | -- |
| Downy serviceberry | 111 | 54 | 111 |
| Chestnut oak | 111 | 54 | -- |
| White ash | 54 | -- | -- |
| Black oak | 54 | 54 | -- |
| Greenbrier | 54 | -- | 385 |
| Virginia pine | -- | 111 | -- |
| Pignut hickory | -- | 54 | -- |
| Hawthorn | -- | 54 | -- |
| Post oak | -- | 54 | -- |
| Fraser Magnolia | -- | -- | 551 |
| Cucumber magnolia | -- | -- | 497 |
| American chestnut | -- | -- | 331 |
| Sourwood | -- | -- | 277 |
| Striped maple | -- | -- | 111 |
| Witch hazel | -- | -- | 111 |
| | **Understory Vegetation Control Plot** | | |
| Blackgum | 220 | 385 | -- |
| White pine | 220 | -- | -- |
| Downy serviceberry | 111 | 111 | 166 |
| Flowering dogwood | 111 | 111 | -- |
| Mockernut hickory | 111 | 111 | -- |
| American chestnut | 54 | -- | -- |
| Red maple | 54 | 111 | 111 |
| Scarlet oak | 54 | -- | -- |
| White oak | 54 | 111 | -- |
| Beaked hazel | -- | 111 | -- |
| Chestnut oak | -- | 54 | -- |
| Greenbrier | -- | 54 | 166 |
| Witch hazel | -- | 54 | 277 |
| Mountain winterberry | -- | 54 | 111 |
| Sourwood | -- | -- | 166 |
| Fraser magnolia | -- | -- | 54 |
| Highbush blueberry | -- | -- | 54 |
| Striped maple | -- | -- | 54 |

**Table D-2.** Pretreatment species density of stems between 1 and 2 meters in height found on the Blacksburg, Fishburn, and Clinch Sites for the Control Treatment Plot.

| | Control Plot | | |
|---|---|---|---|
| | <-------stems per hectare------> | | |
| Species | Blacksburg | Fishburn | Clinch |
| Red maple | 551 | 331 | 385 |
| Scarlet oak | 385 | 166 | -- |
| Downy serviceberry | 331 | 277 | -- |
| Black oak | 220 | 110 | -- |
| White ash | 220 | -- | -- |
| Flowering dogwood | 220 | 277 | -- |
| Mockernut hickory | 166 | 277 | -- |
| Azalea spp. | 111 | -- | -- |
| Yellow-poplar | 54 | -- | -- |
| White oak | 54 | 54 | 2965 |
| Chestnut oak | 54 | -- | -- |
| Northern red oak | 54 | -- | -- |
| Blackgum | 54 | 385 | 111 |
| Sassafras | 54 | 277 | -- |
| Greenbrier | 54 | -- | 385 |
| Deerberry | 54 | 111 | -- |
| Blackhaw viburnum | 54 | -- | -- |
| Mountain laurel | -- | 331 | -- |
| Hawthorne | -- | 166 | -- |
| Bear oak | -- | 166 | -- |
| Beaked hazel | -- | 111 | -- |
| Glaucous greenbrier | -- | 111 | -- |
| Huckleberry | -- | 54 | -- |
| Witch hazel | -- | 54 | -- |
| Rubus spp. | -- | 54 | -- |
| Cucumber magnolia | -- | -- | 662 |
| American chestnut | -- | -- | 166 |
| Sourwood | -- | -- | 111 |
| Low blueberry | -- | -- | -- |
| Striped maple | -- | -- | 277 |

**Table D-3.** Pretreatment species density of stems between 1 and 2 meters in height found on the Blacksburg, Fishburn, and Clinch Sites for the Understory Vegetation Control Treatment Plot.

| | **Understory Vegetation Control Plot** | | |
|---|---|---|---|
| | <-------stems per hectare------> | | |
| Species | Blacksburg | Fishburn | Clinch |
| Downy serviceberry | 331 | 220 | 54 |
| Pignut hickory | 111 | -- | -- |
| Mockernut hickory | 111 | -- | -- |
| Blackgum | 111 | 220 | -- |
| Chestnut oak | 111 | 5436 | -- |
| Flowering dogwood | 111 | 111 | -- |
| Red maple | 54 | 277 | -- |
| White oak | 54 | -- | 4448 |
| Scarlet oak | 54 | 54 | -- |
| Sassafras | 54 | 277 | -- |
| Deerberry | 54 | -- | -- |
| Virginia creeper | -- | 9390 | 54 |
| Greenbrier | -- | 220 | 22733 |
| Beaked hazel | -- | 166 | -- |
| Mountain laurel | -- | 166 | -- |
| Hawthorn | -- | 54 | -- |
| Huckleberry | -- | 54 | -- |
| Witch hazel | -- | 54 | 111 |
| White pine | -- | 54 | -- |
| Virginia pine | -- | 54 | -- |
| Highbush blueberry | -- | -- | 662 |
| Striped maple | -- | -- | 166 |
| Black birch | -- | -- | 111 |
| American chestnut | -- | -- | 54 |
| Cucumber magnolia | -- | -- | 54 |
| American beech | -- | -- | 54 |

**Table D-4.** Pretreatment species density of stems less than 1 year old found on the Blacksburg, Fishburn, and Clinch Sites for the Control and Understory Vegetation Control Treatment Plots.

| | **Control Plot** | | |
|---|---|---|---|
| | <-------stems per hectare------> | | |
| Species | Blacksburg | Fishburn | Clinch |
| Yellow-poplar | 2471 | -- | -- |
| Acer rubrum | 1977 | 2965 | 19274 |
| Sassafras | 1483 | 3459 | -- |
| Black cherry | 988 | -- | -- |
| Greenbrier | 988 | 494 | -- |
| Low blueberry | 988 | 2471 | -- |
| Downy serviceberry | 494 | -- | -- |
| White oak | 494 | -- | -- |
| Scarlet oak | 494 | 988 | -- |
| Azalea spp. | 494 | -- | 494 |
| Mapleleaf viburnum | 494 | -- | -- |
| Striped maple | -- | -- | 7413 |
| Beaked hazel | -- | 988 | -- |
| Mountain laurel | -- | 494 | -- |
| Bear oak | -- | 1483 | -- |
| Black oak | -- | 1977 | 494 |
| Chestnut oak | -- | -- | 1483 |
| Deerberry | -- | 494 | -- |
| Mountain winterberry | -- | -- | 988 |
| Cucumber magnolia | -- | -- | 494 |
| | **Understory Vegetation Control Plot** | | |
| Red maple | 10378 | 988 | 7907 |
| Sassafras | 7907 | 1977 | -- |
| Low blueberry | 6919 | 3459 | -- |
| Downy serviceberry | 4942 | 988 | 3954 |
| Azalea spp. | 4448 | -- | -- |
| White oak | 2965 | -- | -- |
| Deerberry | 2965 | -- | -- |
| Scarlet oak | 2471 | 1483 | -- |
| Black oak | 1483 | -- | -- |
| Black cherry | 494 | -- | -- |
| Greenbrier | 494 | -- | -- |
| Mapleleaf viburnum | 494 | -- | -- |
| Striped maple | -- | -- | 7907 |
| Cucumber magnolia | -- | -- | 988 |
| Flowering dogwood | -- | 1977 | -- |
| Huckleberry | -- | -- | -- |
| Chestnut oak | -- | -- | 1483 |
| Northern red oak | -- | -- | 1483 |

**Table D-5.** Pretreatment species density of stems between 0 and 1 meter in height that are greater than 1 year old found on the Blacksburg, Fishburn, and Clinch Sites for the Control Treatment Plot.

| | **Control Plot** | | |
|---|---|---|---|
| | <-------stems per hectare------> | | |
| Species | Blacksburg | Fishburn | Clinch |
| Azalea spp. | 42501 | -- | -- |
| Low blueberry | 37064 | -- | 494 |
| Deerberry | 32617 | 111 | -- |
| White oak | 14826 | 1483 | -- |
| Red maple | 8895 | 1977 | 26192 |
| Black cherry | 5930 | -- | -- |
| Greenbrier | 5930 | -- | -- |
| Downy serviceberry | 5436 | 4942 | 494 |
| Scarlet oak | 5436 | 3400 | -- |
| Sassafras | 5436 | 277 | 494 |
| Glaucous greenbrier | 4448 | 111 | 1483 |
| Multiflora rose | 3954 | 5436 | -- |
| Mockernut hickory | 2965 | -- | -- |
| Black oak | 2965 | 4448 | 494 |
| Huckleberry | 2471 | 6425 | -- |
| Blackgum | 988 | -- | 1483 |
| Flowering dogwood | 988 | -- | -- |
| White ash | 988 | -- | -- |
| Wild grape | 988 | -- | -- |
| Pignut hickory | 494 | -- | -- |
| Sourwood | 494 | -- | -- |
| Virginia creeper | 494 | -- | -- |
| Mapleleaf viburnum | 494 | -- | -- |
| Beaked hazel | -- | 19274 | -- |
| Bear oak | -- | 5930 | -- |
| Mountain laurel | -- | 3954 | -- |
| Hawthorn | -- | 1977 | -- |
| Rubus spp. | -- | 988 | -- |
| Allegheny chinkapin | -- | 494 | -- |
| Virginia pine | -- | 494 | -- |
| White pine | -- | 54 | -- |
| Striped maple | -- | -- | 7907 |
| American chestnut | -- | -- | 494 |
| Witch hazel | -- | -- | 2965 |
| Cucumber magnolia | -- | -- | 17297 |
| Fraser magnolia | -- | -- | 494 |
| Northern red oak | -- | -- | 1483 |
| Highbush blueberry | -- | -- | 1483 |

**Table D-6.** Pretreatment species density of stems between 0 and 1 meter in height that are greater than 1 year old found on the Blacksburg, Fishburn, and Clinch Sites for the Understory Vegetation Control Treatment Plot.

| | **Understory Vegetation Control Plot** | | |
|---|---|---|---|
| | <-------stems per hectare------> | | |
| Species | Blacksburg | Fishburn | Clinch |
| Low blueberry | 26192 | 46454 | -- |
| Downy serviceberry | 12849 | 5436 | 4448 |
| Azalea spp. | 9390 | 10872 | 5436 |
| Sassafras | 7413 | 22239 | -- |
| White oak | 6425 | 1483 | 3954 |
| Red maple | 5930 | 5930 | 8895 |
| Scarlet oak | 5930 | 4942 | -- |
| Deerberry | 5930 | 6425 | -- |
| Black oak | 2965 | 494 | -- |
| Witch hazel | 2471 | 2965 | 988 |
| Black cherry | 1977 | 2441 | 15876 |
| Mapleleaf viburnum | 1977 | -- | -- |
| American chestnut | 1483 | -- | -- |
| Allegheny chinkapin | 1483 | 3459 | -- |
| Mockernut hickory | 988 | 494 | -- |
| Huckleberry | 988 | 18285 | -- |
| Glaucous greenbrier | 988 | 8401 | 494 |
| Pignut hickory | 494 | -- | -- |
| Black locust | 494 | -- | -- |
| Multiflora rose | 494 | 1977 | -- |
| Greenbrier | 494 | 3954 | -- |
| Beaked hazel | -- | 9884 | -- |
| Rubus spp. | -- | 5930 | -- |
| Flowering dogwood | -- | 3954 | -- |
| Bear oak | -- | 2471 | -- |
| Hawthorn | -- | 494 | -- |
| Mountain laurel | -- | 494 | -- |
| Blackgum | -- | 494 | 988 |
| Wild grape | -- | 494 | -- |
| Striped maple | -- | -- | 3954 |
| Cucumber magnolia | -- | -- | 7907 |
| Fraser magnolia | -- | -- | 988 |
| Highbush blueberry | -- | -- | 988 |

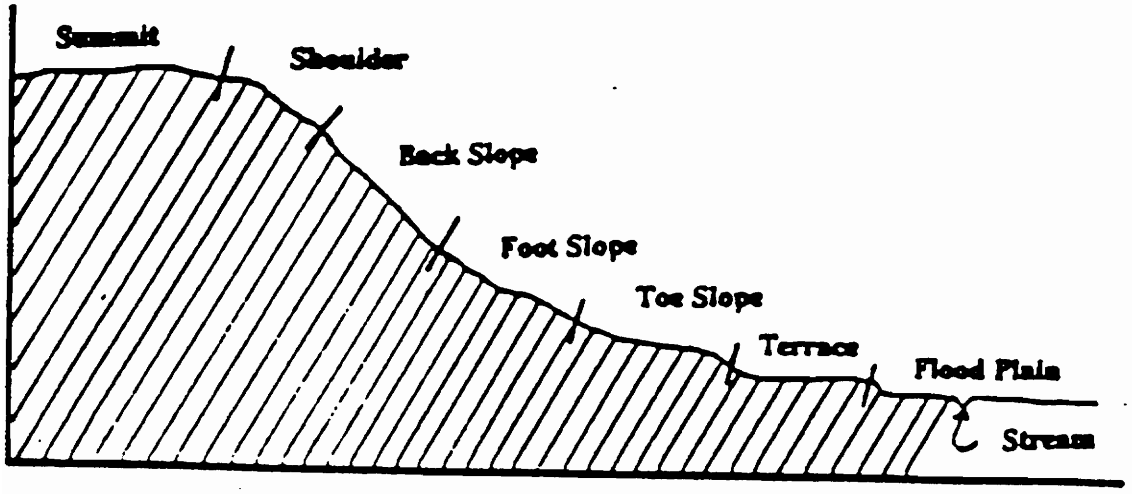
**APPENDIX E**

**FSQI CALCULATION**

Slope, Aspect and Slope Position value ranges with the respective FSQI rank values used in the calculation of FSQI: A rank of 1 indicates the lowest in site quality.

| Slope (%) | Aspect(Deg.) | Slope Position | Ranking |
|---|---|---|---|
| >60 | 196 - 260 | shoulder | 1 |
| 45 - 69 | 166-195, 261-280 | backslope[1] | 2 |
| 30 - 44 | 146-165, 281-340 | summit | 3 |
| 15 - 29 | 000-020, 341-360 | footslope | 4 |
| 0 - 14 | 081-145 | toeslope, | |
| " | " | terrace, and | |
| " | " | floodplain | 5 |
| - | 021-080 | - | 6 |

[1] The Backslope slope position is further divided into upper and lower and ranked 2 and 3, respectively.



**APPENDIX F**

## Special Sampling Situations

***Subplots:***

1) If a sprout clump was located in a subplot it was counted as a single stem if the sprouts were separate above the A horizon.

2) If a sprout clump was located such that part of the clump was 'in' and part of the clump was 'out' then it was treated as 'in' if greater than half the original 'stump' was in the plot; the above rule still holds with regard to the number of stems to count.

3) Only stems that originate from within subplots were counted as 'in' (*ie.* if the root collar was located in the plot then the stem was counted as 'in,' otherwise it was counted as 'out').

4) Stems were termed as new seedlings if they germinated in the same year as sampling occurred; For species that root sprout (e.g. sassafras) a stem was considered a new seedling if the shoot was clearly less than one year old.

***Point sampling:***

Trees that fork below 4.5 ft were counted as two stems given that both stems were 'in.'

***Height of individuals:***

1) Height was measured on the uphill side of the stem

with the base of the stem (no greater than 1 ft. above ground) being held upright vertically. Height was measured to the top of the tallest live bud on the stem after being straightened.

2) If the height of the stem, when straightened, was smaller than if not straightened then the stem was extended to its full length (without causing damage to the stem) and height from the ground to the tallest bud was measured (this occurs rarely).

3) If for some reason the stem could not be straightened, such as an obstruction, then the height was measured diagonally along the stem from the base of the stem to the tallest bud.

4) If the stem forked at, or near, ground level then the height of the tagged stem was measured.

***Diameter of individuals:***

1) If have a seedling sprout-origin that sprouted at or near ground level, then the groundline diameter and the diameter of the sprout attached to the original stem was measured.

2) If have a seedling that has lost its original top, but still retained one or more live branches, then only the groundline diameter was measured.

3) If have a stump sprout-origin stem and the groundline diameter could not be measured because of

the presence of the stump then the diameter was measured at the point of attachment to the stump.

4) If the stem was forked at or near groundline, the average groundline diameter was measured along with the diameter of the tagged portion of that stem.

***Origin of individuals:***

Definitions used to determine stem origin:

**True Seedling (S)**: any stem that originated from seed and has not died-back from the root collar. This includes stems whose original top died, but has an original lateral branch remaining alive.

**Seedling sprout (SS)**: any stem originating from a root stock that appears older than the stem itself and the groundline diameter of the 'stump' is less than 2 inches. This does not include stems whose original top died, but an original lateral branch remained alive on the stem.

**Stump sprout (STS)**: A sprout-origin stem that has an original stump diameter at groundline greater than 2 inches.

***Competition sampling around individuals:***

**Note**: Species noted below as being counted were tallied by .1 m height classes; Species grouped by cover class were not tallied by height class.

1) All arborescent species were counted.

2) The following shrub species were counted if greater than 1 m in height. **Note:** Do not straighten to determine if stem exceeds 1 meter in height (if less than 1 m in height then a cover class was assigned):

a) huckleberry and vaccinium species (grouped together) and

b) rhododendron species.

3) The following shrub species were counted regardless of height:

a) Viburnum species,

b) Beaked hazel,

c) Mountain laurel, and

d) Rose species.

4) Vine species were grouped and assigned a cover class.

***Other situations in competition sampling:***

1) Trees (stems > 5m tall) forking below DBH were counted separately in stem count.

2) Trees with a shrub (stems 2 to 5 m tall) attached below 4.5 ft were counted as a tree and a shrub.

3) Stems forking below mineral soil were counted separately.

4) Sprout-origin stems (including 'water sprouts' from the base of living trees) with multiple sprouts (sprouting above ground level) were counted as one stem

and the height of the tallest stem in sprout clump was measured.

5) Stems placed in height classes were fully extended.

## APPENDIX G

**Table G-1.** Number of seedlings included in the subsample for the Understory Vegetation Control (UVC) and Control Treatments and the 0 to 1 m and 1 to 2 m Height Classes by Species Group for the percent seedling mortality analysis.

| Treatment/ Height Class | Species Group: Maple | Red Oak | White Oak |
|---|---|---|---|
| UVC | 113 | 110 | 110 |
| Control | 115 | 115 | 114 |
| 0 to 1 m | 132 | 151 | 144 |
| 1 to 2 m | 96 | 74 | 80 |

**Table G-2.** Number of seedlings included in the subsample for the Understory Vegetation Control (UVC) and Control Treatments by Species Group for the relative seedling height growth analysis.

| Treatment | Species Group: Maple | Red Oak | White Oak |
|---|---|---|---|
| UVC | 92 | 104 | 89 |
| Control | 104 | 97 | 90 |

**VITA**

Jesse Warren Thompson was born on March 6, 1968 in San Diego, California. He enlisted in the Virginia Army National Guard in 1986 and served as an Infantryman for 6 years. He received his B.S. in Forest Resource Management from Virginia Tech in 1993 and married Mitzi Janine DeHart that same year.