Underplanted shortleaf pine seedling survival and growth in the North Carolina Piedmont

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A study was established to evaluate underplanting as a method of reestablishing shortleaf pine (*Pinus echinata* Mill.) in the Piedmont Region of North Carolina. Replicated treatment plots were harvested to retain 0, 15, 30, or 45 square feet of basal area per acre. Bareroot and containerized stock with small and large plugs were established within the treatment plots. Large plug seedlings achieved the highest first year survival followed by the small plug and bareroot seedlings. Underplanted seedling growth was inversely related to residual overstory density after two growing seasons. Large plug seedlings achieved the greatest height and diameter growth, followed by the small plug and bareroot seedlings. The results of this study suggest that underplanting may be a suitable regeneration option for the initial establishment of shortleaf pine on Piedmont sites. Further improvements in seedling survival and growth may be realized by planting containerized seedlings with large plugs.
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# TABLE OF CONTENTS

**ACKNOWLEDGEMENTS** .................................................................................................................. ii  
**LIST OF TABLES** .......................................................................................................................... v  
**LIST OF FIGURES** ........................................................................................................................ vi  
**CHAPTER**

**I. INTRODUCTION** ......................................................................................................................... 1  
1.1 Objectives and Hypotheses ............................................................................................................. 4  
1.1.1 Objective One ............................................................................................................................. 4  
1.1.2 Objective Two ............................................................................................................................. 4  
1.1.3 Objectives Three and Four ......................................................................................................... 4  

**II. LITERATURE REVIEW** .............................................................................................................. 5  
2.1 General Ecological Characteristics ................................................................................................. 5  
2.2 Damaging Agents ............................................................................................................................. 8  
2.3 Regenerating Shortleaf Pine ........................................................................................................... 10  
2.3.1 Natural Regeneration ............................................................................................................... 11  
2.3.2 Artificial Regeneration ............................................................................................................. 13  
2.4 Seedling Production and Stock Type Performance ......................................................................... 16  
2.5 Bareroot vs. Containerized Stock ................................................................................................. 19  

**III. MATERIALS AND METHODS** .................................................................................................. 22  
3.1 Study Site ....................................................................................................................................... 22  
3.2 Treatments and Implementation ..................................................................................................... 25  
3.3 Measurements ................................................................................................................................. 29  
3.4 Statistical Analysis .......................................................................................................................... 30  

**IV. RESULTS** ................................................................................................................................. 32  
4.1 Initial Seedling Size ......................................................................................................................... 32  
4.2 Residual Overstory Basal Area ....................................................................................................... 33  
4.3 Survival .......................................................................................................................................... 35  
4.4 Growth .......................................................................................................................................... 37  
4.4.1 Height growth ............................................................................................................................... 37
4.4.2 Groundline Diameter Growth ............................................................ 40
4.5 Deer and Sawfly Damage ................................................................. 42

V. DISCUSSION ......................................................................................... 45

5.1 Survival and Growth ......................................................................... 45
  5.1.1 Overstory Basal Area ................................................................. 45
  5.1.2 Stock Type ................................................................................ 48
5.2 Deer Browse and Sawfly Damage .................................................... 51

VI. CONCLUSIONS .................................................................................... 53

REFERENCES .............................................................................................. 55
### LIST OF TABLES

4.1 F-tests for main effects stock type and residual overstory basal area (RBA) on initial seedling height and GLD .................................................................32

4.2 Tukey-Kramer adjustment for multiple comparisons of LS means for the effect of Stock Type on initial seedling height and GLD ..........................33

4.3 Overstory basal area at the time of planting (RBA_0) and following the first (RBA_1) and second (RBA_2) growing seasons by block and treatment .................................................................34

4.4 F-tests for main effects stock type and residual overstory basal area on seedling survival ........................................................................................35

4.5 Tukey-Kramer adjustment for multiple comparisons of LS means for the effect of Stock Type on percent mean seedling survival ..........................35

4.6 Effects of overstory basal area on percent seedling survival after one growing season by stock type .................................................................36

4.7 F-tests for main effects residual overstory basal area (RBA) and stock type on seedling height and GLD growth after two growing seasons ..........38

4.8 Tukey-Kramer adjustment for multiple comparisons of LS means for the effect of Stock Type on seedling height and GLD growth after two growing seasons .................................................................39

4.9 Effects of residual overstory basal area on seedling height and GLD growth after two growing season by stock type .................................................................39

4.10 Effects of residual overstory basal area on percent of seedlings browsed by deer or damaged by sawfly after one growing season by stock type .................................................................43

4.11 Tukey-Kramer adjustment for multiple comparisons of LS means for the effect of Stock Type on deer browse after one growing season ..........43

4.12 F-tests for main effects residual overstory basal area on percent deer browse after one growing season for large plug, small plug and bareroot stock types .................................................................44
LIST OF FIGURES

3.1 Location of the study site on the Umstead Research Station in relation to the Central Appalachian Piedmont Region .......................................................23

3.2 Arrangement of Residual Basal Area Treatments by Block on the Study Site................................................................................................................26

3.3 Residual overstory basal area treatment plot and seedling measurement plot originating from plot center ...............................................................28

4.1 Effects of residual overstory basal area on seedling survival after one growing season for large plug, small plug, and bareroot seedlings........37

4.2 Effects of residual overstory basal area on mean seedling height growth after two growing seasons for large plug, small plug, and bareroot stock types.................................................................40

4.3 Effects of residual overstory basal area on mean seedling GLD growth after two growing seasons for large plug, small plug, and bareroot stock types........................................................................42
CHAPTER I
INTRODUCTION

The shortleaf pine (*Pinus echinata* Mill.) component of forests in the eastern United States has been declining for the past several decades (Moser et al. 2007; Oswalt, 2012). Oswalt (2012) analyzed data from the national Forest Inventory and Analysis Program (FIA) of the United States Forest Service and reported a region-wide loss of 52 percent of the acreage classified as shortleaf pine and shortleaf pine-oak forest-types between 1980 and 2010. In addition to the documented losses in acreage, further investigation of the FIA data reveals that the remaining shortleaf pine-dominated forests are comprised mostly of large diameter trees and that shortleaf pine regeneration is not present in large quantities (Moser et al., 2007; Oswalt, 2012). These trends point to continued losses of the shortleaf pine resource from eastern forests (Moser et al., 2007; Oswalt, 2012).

There is now growing interest in restoring mixed shortleaf pine-hardwood forests across much of the native range of shortleaf pine. In addition to providing habitat for migratory birds and a variety of other wildlife species, mixed forests may be an alternative to managing oak (*Quercus* spp.)-dominated stands where chronic oak decline is or may become an issue (Blizzard et al., 2007). Hardwood species are also a natural part of many forests within the range of shortleaf pine (Lawson, 1990). This is especially true in the Central Appalachian Piedmont Region where descriptions of ecological
communities and historic accounts suggest that shortleaf pine existed primarily as a component of hardwood-dominated mixtures, occasionally and often only temporarily obtaining co-dominance in xeric ecological communities (Barden, 1997; Flemming and Patterson, 2013; Schafale, 2013). In addition to the ecological objectives which may favor the selection of shortleaf pine, forgoing expensive hardwood control options and allowing a pine-hardwood mixture to develop may also be a low cost method of managing forests that provide multiple benefits (Phillips and Abercrombie, 1987; Waldrop, 1997).

Unfortunately, research pertaining to the silvicultural practices needed to develop and maintain pine-hardwood mixtures lags behind that of managing pure shortleaf pine or other mixed pine forest types (Guldin, 2007). Despite its economic and ecological importance, shortleaf pine has historically received less attention in research and silvicultural practice compared to slash (P. elliottii), loblolly (P. taeda), and longleaf pines (P. palustris) (Barnett and Brissette, 2007; Mexal, 1992). Much of the published research on regenerating and managing shortleaf pine, as well as managerial knowledge gained through practice, has focused on regenerating pure, even-aged stands. Research focused on establishing pine-hardwood mixtures with a shortleaf pine component is comparatively sparse and almost exclusively limited to sites from the western extent of the native range of shortleaf pine.

Previous research suggests that underplanting shortleaf pine seedlings beneath a residual hardwood overstory may be a viable regeneration option for some forest landowners (Guldin and Heath, 2001; Jensen and Gwaze, 2007; Jensen et al., 2007; Kabrick et al., 2011). Retaining residual overstory basal area can limit the negative visual
impacts of timber harvesting (Olson et al., 2015). Additionally, the retained overstory can partially control woody and herbaceous competition and reduce the need for release herbicides (Jensen et al., 2007). Underplanting may therefore be a suitable regeneration approach for the rapidly developing Central Appalachian Piedmont Region where public opinion and changing landowner values can limit the use of many intensive southern pine regeneration methods that include clearcut harvesting and herbicide applications. Unfortunately, research pertaining to this approach for shortleaf pine has been conducted primarily in Arkansas and Missouri, over 500 miles west of the Central Appalachian Piedmont region. As such, a localized study to determine whether the method is successful under the climatic and edaphic conditions of the Central Appalachian Piedmont region is warranted.

In 2012, the North Carolina Department of Agriculture and Consumer Services Research Stations Division (NCDA&CS-RSD) applied several components of previous underplanting studies from Arkansas and Missouri to a site on the North Carolina Piedmont. Three different shortleaf pine stock types were underplanted beneath varying levels of residual hardwood overstory basal area on an adverse but not uncommon North Carolina Piedmont site. The study allows the exploration of four specific objectives to achieve the primary goal of evaluating the effectiveness of underplanting as a method of reestablishing a shortleaf pine component to pine-hardwood mixtures in the Central Appalachian Piedmont.
1.1 Objectives and Hypotheses

1.1.1 Objective One

The first objective is to evaluate the impact of residual overstory basal area on the survival and growth of underplanted seedlings. Based on the findings of previous research, residual overstory basal area is not predicted to have a significant effect on 1st-year seedling survival. However, residual overstory basal area is expected to have a significantly negative effect on seedling growth.

1.1.2 Objective Two

The second objective is to evaluate differences in survival and growth between underplanted containerized and bareroot shortleaf pine planting stock. Containerized seedlings are predicted to achieve superior survival and growth compared to bareroot seedlings. Additionally, containerized seedlings with larger plugs are expected to achieve better survival and growth compared to containerized stock with smaller plugs and bareroot stock.

1.1.3 Objectives Three and Four

Objectives three and four have been added post-hoc following site damage by deer browsing and redheaded sawfly (Neodiprion lecontei) defoliation. The third and fourth objectives are to measure the effects of residual overstory basal area and stock type on deer browse and sawfly damage. Neither residual overstory basal area nor stock type are predicted to affect percent deer browse or percent sawfly damage.
CHAPTER II
LITERATURE REVIEW

2.1 General Ecological Characteristics

Shortleaf pine is a commercial species in the taxonomic subsection *Australes* collectively known as the southern yellow pines (Guldin, 1986). Related species of this subsection in the Continental United States include loblolly, longleaf, slash, pitch (*P. rigida* Mill.), spruce (*P. glabra* Walt.), table mountain (*P. pungens* Lamb.), and pond (*P. serotina* Michx.) pines. Characterized as large trees often with straight trunks and broad and open crowns, shortleaf pine is similar in appearance and commercial use to many of its *Australes* cousins. However, shortleaf pine can be differentiated from the other southern yellow pines by its slender and flexible 2.75 to 4.5-inch needles which are bundled most often in two, occasionally three, and rarely four needles per fascicle, reddish-brown bark which often has large, flat and irregularly-shaped plates with cinnamon-red scales, and small 1.5 to 2.5-inch armed cones (Detwiler, 1916).

The native range of shortleaf pine encompasses over 440,000 square miles (Little, 1971) giving it the most expansive native range of the southern yellow pines (Lawson, 1990). Shortleaf pine tends to grow in regions where the average annual precipitation exceeds 40 inches and the average temperature is over 50 degrees Fahrenheit (Fowells, 1965). Average temperatures therefore limit the northern expansion of the species beyond the 50 degree isoline and rainfall limits westward expansion into the dry Great Plains.
where annual precipitation falls below 40 inches (Guldin, 1986). The species can be found as high as 3,000 feet in the southern Appalachian Mountains and 2,000 feet in the Ozarks, Ouachita, and Boston Mountains (Lawson, 1990). While the native range of shortleaf pine falls within 22 states including all of the southern states as well as portions of Illinois, Missouri, New Jersey, New York, Ohio, Pennsylvania, and west into the highlands of Oklahoma, shortleaf pine achieves its best development in Arkansas, northern Louisiana, and the southern Piedmont (Lawson, 1990).

Shortleaf pine is monecious and readily regenerates by seed (Krugman and Jenkinson, 1974). The species is categorized as shade-intolerant, although shortleaf pine can become established and persist under high residual overstory densities (Guldin et al., 2004; Stambaugh, 2001). Growth in the early stages of shortleaf pine seedling establishment is focused on development of the root system instead of rapid height growth (Fowells, 1965) earning shortleaf pine its reputation as a slow grower relative to its fellow southern pines. The root systems of shortleaf pine can be substantial (Mattoon, 1915) and trees with deep, well-developed root systems that include a taproot achieve superior height growth over trees with predominantly lateral root systems (Harrington et al., 1987). Once the root system is established and the trees are free from overstory competition, shortleaf pine growing on productive sites can achieve heights of over 100 feet, diameters over 40 inches DBH, and nearly 400 years of age (Lawson, 1990). Both young and mature trees can respond favorably to release or density management (Fowells, 1965).

A particularly interesting characteristic of shortleaf pine is the ability of its seedlings to regenerate through a unique physiological adaptation known as a “basal
crook.” This unique J-shaped crook forms just above the root collar when the stem emerges from the seed, falls prostrate for a period of two to three months, and then begins to grow upright (Lawson, 1990). The basal crook contains primary needles and their axillary buds which can sprout if the seedling is top-killed (Walker and Oswald, 2000). This unique adaptation places shortleaf pine in position to sprout back rapidly following disturbance such as fire (Fowells, 1965), although shortleaf pine’s sprouting ability decreases with fire intensity and increasing seedling size (Lilly et al., 2012). Shortleaf pine’s early development of a strong root system and temporary tolerance of overstory shade, coupled with the species’ sprouting abilities, is similar to the growth dynamics of various species of oaks (Quercus spp.) with which shortleaf pine is commonly associated in mixed stands (Guldin, 2007).

Shortleaf pine performs best on well-drained fine sandy loams or silt loams that are at least nine inches deep with a subsurface of friable soils (Fowells, 1965). Unfortunately, these conditions are often located on floodplains where species with more rapid early height growth may out-compete shortleaf pine (Fowells, 1965; Guldin, 1986). Deep soils found on upland sites are also very productive for shortleaf pine but the dominance of shortleaf pine on such sites is usually short lived preceding replacement by hardwood species (Guldin, 1986). Shortleaf pine most often maintains dominance on drier uplands, ridge tops, and south-facing slopes underlain by thin rocky soils (Guldin, 2007). Shortleaf pine’s potentially expansive root systems (Mattoon, 1915), comparatively low nutritional needs (Fowells, 1965), and ability to show growth responses to both late season rain and mild winter temperatures (Guyette et al., 2007) can improve its ability to compete with or maintain dominance over competitors on these
often more xeric sites with higher potential evapotranspiration and moisture stress (Guyette et al., 2007). Shortleaf pine is intolerant of soils that are alkaline or have high calcium content, or soils that are excessively well-drained (Fowells, 1965).

The expansive native range and ecological characteristics of shortleaf pine contribute to its existence with varying levels of dominance in 18 different Society of American Foresters forest types and 85 USDA Forest Service forest-type groups (Lawson 1990; Moser et al., 2007). Shortleaf Pine (Type 75), Shortleaf Pine-Oak (Type 76), and Loblolly-Shortleaf Pine (Type 80) are types in which shortleaf pine is a major component (Lawson, 1990). Shortleaf pine is also commonly found growing as a minor component in several other pine forest types with species including loblolly, longleaf, Virginia (P. virginiana Mill.), pitch, and eastern white pine (P. strobus L) as well as a component in several hardwood cover types containing mixtures of oaks (Quercus spp.) and hickories (Carya spp.) (Lawson, 1990). Historically, shortleaf pine was also the dominant pine in the fire-driven shortleaf pine/bluestem ecosystems of Arkansas, Oklahoma, and Missouri as well as the open woodlands which once occupied portions of the Piedmont (Barden, 1997).

2.2 Damaging Agents

Shortleaf pine health may be negatively impacted by a wide variety of biotic and abiotic disturbances. Pales weevil (Hylobius pales), pitch-eating weevil (Pachylobius picivorus), and the Nantucket pine tip moth (Rhyacionia frustrana), can cause severe damage to newly-planted seedlings and reduce volume growth (Baker, 1972; Flavell, 1974; Lawson, 1990). Several bark beetles, including southern pine beetle (Dendroctonus frontalis), pine engraver or “Ips” beetle (Ips spp.), and the black turpentine beetle
(Dendroctonus terebrans) can lead to substantial losses of shortleaf pine by phloem feeding and eventually girdling mortality (Lawson, 1990).

Redheaded sawfly (Neodiprion lecontei) and loblolly pine sawfly (Neodiprion taedae linearis) both impact shortleaf pine. Redheaded sawfly prefers stressed trees that are less than 15 feet tall and are most often found on trees growing on poor soils, where there is heavy herbaceous competition, and along the edges of hardwood forests (Wilson and Averill, 1978). Defoliation can lead to mortality but southern pines including shortleaf pine are often able to survive total defoliation by the insect (Lawson, 1990). Wilson and Averill (1978) reported that moderate to heavy redheaded sawfly defoliation can stunt height growth of infested trees. Land and Rieske (2006) explored arthropod herbivory specifically on shortleaf pine and found that it did not impact seedling growth. However, much of the herbivory results analyzed by Land and Rieske (2006) were caused by arthropod species other than redheaded pine sawfly. Land and Rieske (2006) also found that prescribed burning reduced the prevalence of redheaded pine sawfly, presumably by eliminating the prepupae that overwinters in topsoil. In addition to prescribed burning, chemical controls, proper species selection for reforesting cutover sites, and natural controls like rodent predation and native diseases can mitigate the damage caused by sawflies (Baker, 1972; Flavell, 1974; Land and Rieske, 2006; Lawson, 1990).

A variety of mammals including rabbits, deer, and others regularly browse planted or naturally-regenerated pine seedlings (Little and Mohr, 1954; Shelton and Cain, 2002). There is very little research focused specifically on shortleaf pine, but Little and Mohr (1961) found that deer browse on loblolly pine can set growth back by one to two
years before the seedlings are able to sprout and recover. Cain and Shelton (2002) simulated deer browse on one year-old naturally-regenerated loblolly pine seedlings and determined that recovery strongly depends on the extent of damage. Seedlings clipped in the winter recovered better than those clipped in the spring and recovery was good for seedlings clipped above the cotyledons. Seedling growth was unfortunately still reduced by 40% during the growing season immediately following the simulated browse. However, studies by Hunt (1968) and Wakeley (1970) found that growth reductions caused by browsing dissipate as the stands age and the seedlings recover. Approximately 11% of underplanted shortleaf seedlings in Kabrick et al. (2011) experienced browse damage. The browsed seedlings were found to have significantly reduced shoot growth compared to seedlings which had not been browsed. Diameter growth was not affected by browse (Kabrick et al., 2011).

2.3 Regenerating Shortleaf Pine

Shortleaf pine can be regenerated through both natural and artificial means. Baker (1992), Lawson (1986), and Dennington (1992), provide thorough overviews of the seed production, dispersal, and silvicultural techniques often needed to naturally regenerate even or multi-aged stands of shortleaf pine through the careful application of reproduction cutting methods including clearcutting, seed tree, shelterwood, single-tree selection, and group selection harvesting. A thorough review of artificial regeneration methods aimed at establishing pure, even-aged stands of shortleaf pine may be found in Barnett and Brissette (2007), Mexal (1992), and Barnett et al. (1986).
2.3.1 Natural Regeneration

Several studies have investigated reproductive cutting methods that retain mixtures of pine and hardwood species in an effort to naturally regenerate mixed even and uneven-aged stands (Jensen and Kabrick, 2008; Guldin et al. 2004). Jensen and Kabrick (2008) evaluated oak and shortleaf pine regeneration following the application of clearcut, group selection, and single-tree selection regeneration harvests in the Missouri Ozarks. None of these methods resulted in the successful natural regeneration of shortleaf pine as a component of mixed stands. Jensen and Kabrick (2008) attributed the low density of pine regeneration to competition from the abundant hardwood sprouting in the group selection and clearcut treatments as well as the high levels of overstory shade and too little ground scarification under the single-tree selection harvest treatments.

Jensen and Kabrick (2008) suggested that additional site preparation and competition control would likely be necessary to increase pine densities under reproductive cutting methods aimed at regenerating mixed stands. Cain and Shelton (2000) tested prescribed fire as a way to control hardwood sprouts in naturally regenerated stands but found that oak sprouts had better survival and more rapid growth following the burn than the shortleaf pine seedlings. Fortunately, chemical treatment of competing hardwoods and herbaceous competition has been shown to be an effective method of control (Amishev and Fox, 2006; Yeiser, 1992; Yeiser and Barnett, 1991; Kushla, 2009; Cain, 2004) and shortleaf pine seedlings respond favorably to release (Cain, 2004).

Guldin et al. (2004) evaluated shortleaf pine regeneration after five growing seasons under 13 different reproductive cutting methods including clearcuts, group
selection, and several variations of seed-tree, shelterwood, and single-tree selection harvests. These harvests were applied to overstories of pine and pine-hardwood mixtures in the Interior Highlands of Arkansas and Oklahoma. Similar to Jensen and Kabrick (2008), Guldin et al. (2004) found that group selection harvesting did not result in acceptable levels of shortleaf pine regeneration. However, acceptable levels of shortleaf pine regeneration and growth did occur under the clearcut and several of the shelterwood methods. Interestingly, acceptable shortleaf pine regeneration and height growth was measured under several of the single-tree selection methods which had over 60 square feet of residual basal area. Shortleaf pine seedlings were also able to become established and persist under the uncut control which had approximately 130 square feet or residual basal area, although the seedlings grew very little under such a high overstory density (Guldin et al., 2004). Guldin et al. (2004) noted that further research should explore whether or not acceptable levels of shortleaf pine regeneration and stocking can be maintained as the residual overstories continued to grow.

Shelton and Baker (1992) investigated uneven-aged management in pine and pine-hardwood mixtures in the Ouachita Mountains of Arkansas and Oklahoma. After two growing seasons following overstory manipulation, pine regeneration under the pine only stands was greater than regeneration under the pine-hardwood mixtures. Shelton and Murphy (1997) assessed regeneration on the same site three years after overstory manipulation and found that the stocking and size of shortleaf pine seedlings decreased with increasing amounts of overstory hardwoods. The same trends continued when regeneration was assessed six years after overstory manipulation (Shelton 2004). One
noted advantage to retaining the hardwood component was less competing vegetation in the understory following the overstory manipulations (Shelton and Baker, 1992).

Shelton and Baker (1992) measured light intensity beneath the pine only and an equivalent basal area of pine-hardwood. Light intensity under the pine only canopy was approximately 60%, while the mixed pine and hardwoods had only 25% light intensity. Shelton and Murphy (1997) present a simpler description of the difference between pine and hardwood canopies, suggesting that one square foot of overstory hardwood basal area is estimated to have the suppressing power of two square feet of overstory pine.

### 2.3.2 Artificial Regeneration

Studies have also examined ways to artificially regenerate shortleaf pine as a component of the pine-hardwood mixtures (Guldin, 2007). A mixed stand regeneration technique often referred to as the fell-and-burn technique has been shown to promote the development of pine-hardwood mixtures on many sites (Waldrop, 1997; Phillips and Abercrombie, 1987; Boggs and Wittwer, 1993). The aptly named fell-and-burn technique involves harvesting the overstory and allowing stump sprouts to develop. The stump sprouts are then brush sawn during the growing season when leaves are present and severed stems are left scattered across the stand as fuel. Once new stump sprouts begin to develop, the stand is burned and pine seedlings are outplanted across the site. Phillips and Abercrombie (1987) achieved shortleaf pine seedling survival rates between 68% and 92% after four growing seasons in the Southern Appalachians using the fell-and-burn technique. Waldrop (1997) achieved between 58% and 74% percent loblolly pine survival after six growing seasons by employing variations of the fell-and-burn technique on xeric sites in the Georgia Piedmont.
Underplanting shortleaf pine seedlings beneath mature hardwood forests and controlling the density and composition of the overstory may also be an effective method of restoring the shortleaf pine component to mixed stands. Guldin and Heath (2001) underplanted bareroot shortleaf pine seedlings under a previously thinned hardwood overstory of at least 40 square feet per acre in the Ouachita Mountains of Arkansas. Once the seedlings had been in place for three growing seasons, the overstory was reduced in ten square foot increments from 40 to 0 square feet of residual overstory basal area per acre. Seedling survival prior to the overstory treatment in year three ranged from 64% to 85% and overstory density did not have a significant effect on seedling survival after seven growing seasons. However, overstory basal area did have a significant effect on underplanted shortleaf pine growth. Seedling growth was inversely related to overstory density (Guldin and Heath, 2001).

Jensen et al. (2007) underplanted bareroot shortleaf pine seedlings beneath a mature hardwood overstory in the Missouri Ozarks and then applied clearcut, group selection, or shelterwood harvests retaining B or C-level stocking (Gingrich, 1967) as overstory treatments a few months after planting. Seedling survival in the clearcut plots (76%) and shelterwood harvest with B-level stocking (62%) was significantly better than survival under the shelterwood with C-level stocking (34%) and group selection harvests (14%) after seven growing seasons. Seedling height growth was best in the clearcut plots and declined through the group selection and shelterwood treatments with C-level and B-level stocking. Midstory hardwood competition also decreased with increasing basal area but underplanted shortleaf pine growth was still best in the clearcut plots in spite of the
abundant hardwood competition indicating that overstory competition has the greatest effects on underplanted pine seedling survival and growth (Jensen et al., 2007).

Jensen and Gwaze (2007) also underplanted bareroot shortleaf pine seedlings in the Missouri Ozarks and then conducted group selection, clearcut, or shelterwood harvests shortly after planting. They also planted seedlings in a plot which had already been clearcut. Seedling stocking was highest under the group selection harvest treatments, followed by the clearcut and shelterwood treatments. Height growth was inversely related to overstory stocking and was greatest in the clearcut treatment and poorest under the shelterwood treatment. Seedling stocking and growth were better in the plots which had been clearcut and then planted than in the plots which had been underplanted and then clearcut. However, the differences were not significant, indicating that underplanting prior to total overstory removal may be as effective as traditional clearcutting and planting for regenerating shortleaf pine (Jensen and Gwaze 2007).

Kabrick et al. (2011) conducted a study in Missouri investigating early survival and growth of shortleaf pine seedlings underplanted beneath different residual hardwood overstory densities. Unlike the underplanting studies conducted by Guldin and Heath (2001), Jensen et al. (2007) and Jensen and Gwaze (2007), Kabrick et al., (2011) underplanted bareroot shortleaf pine seedlings after the hardwood overstory had been thinned to desired species compositions and stocking levels ranging from 0% to 80%. Survival rates averaged 76% and there were no significant differences by overstory treatment, which is similar to the results of Guldin and Heath (2001), yet in contrast to Jensen et al. (2004). Similar to Guldin and Heath (2001), Jensen et al. (2007) and Jensen and Gwaze (2007), Kabrick et al. (2011) also found an inverse relationship between
overstory stocking and underplanted shortleaf pine growth with the best growth being achieved at the lowest stocking levels.

2.4 **Seedling Production and Stock Type Performance**

Artificial regeneration success may be aided through selection of high-quality seedlings that are suitable for a given site (Mexal, 1992). Once an appropriate seedling family and stock type are selected, special care must be taken to ensure that seedlings are appropriately handled and stored at the nursery, transported to the site, and stored at the site prior to planting. A final and critically important step to artificial regeneration is ensuring that seedlings are not only planted during favorable conditions, but that appropriate equipment and planting techniques are used. These steps along with silvicultural systems which include adequate site preparation, competition control, and the selection of an appropriate planting density all play major roles in the establishment and long-term growth and development of southern pine stands (Mexal, 1992; Barnett et al., 1986; Barnett and Brissette, 2007).

Schmidtling (2001) developed general guidelines for selecting the appropriate seed sources for artificially regenerating southern pines across their native or established ranges, which often span several ecoregions where they experience different climatic conditions. Shortleaf pine seedling survival and growth are best if the seed source originates from an area where the average minimum temperature of the source location and planting site do not deviate by more than 5°F. Seedlings originating from areas with warmer winters will typically grow faster than seedlings originating from areas with cooler winters. With the exception of loblolly pine, for which clear east-west geographic
variation exists, the other southern pines including shortleaf pine may be transferred east
to west (Schmidtling, 2001).

Seedling quality can be assessed by examining material and performance
attributes (Ritchie, 1984). Material attributes are often easy to measure through direct or
indirect methods and are the basis for seedling grading standards (Wakeley, 1954).
Material attributes include root collar diameter, plant moisture stress, dry weight,
dormancy status, and foliar nutrient content (Barnett et al., 1986; Ritchie, 1984).
Performance attributes include cold hardiness, stress resistance, and root growth potential
and often include functions of subsystems comprised of several material attributes like
nutrients and shoot to root ratio (Ritchie, 1984).

Bareroot shortleaf pine seedlings are considered adequate when they have heights
between 6-10 inches, root collar diameters of approximately 0.1-0.2 inches, and a dry
weight root to shoot ratio of four to one. The taproot should be approximately 4-8 inches
long and should contain an abundance of fibrous roots and mycorrhizal colonization
(Barnett et al., 1986). Barnett et al. (1986) and Barnett (1992) suggest that stems should
be woody, a terminal bud should have formed before early November, and the foliage
should be comprised mostly of secondary needles. However, Hallgren and Tauer (1989)
found that the presence of a terminal bud and secondary needles were not valuable
predictors of seedling performance. Chapman (1948) suggested that seedlings should
have approximately 0.1 inches of stem diameter roughly 1 inch above the groundline to
account for the impact that the basal crook can have on root collar diameter. More recent
target bareroot seedling sizes tend to be larger with heights between 10 and 12 inches and
average root collar diameters of approximately 0.2 inches (Conn, 2012). Bell (2012)
recommends that containerized shortleaf pine seedlings have heights of 8 to 10 inches, root collar diameters of approximately 0.15-0.2 inches, and a firm and intact plug.

Many material and associated performance attributes can be influenced through tree improvement and effective nursery production or cultural practices. A thorough review of nursery practices for producing bareroot seedlings for many species, including shortleaf pine, can be found in Duryea and Landis (1984). Several studies have investigated the effects of nursery or other cultural practices in obtaining the targeted shortleaf pine seedling specifications. Low planting bed seedling density has been found to increase shoot length, stem diameter, root volume, and root growth potential in shortleaf pine (Brissette and Carlson, 1992). Nitrogen fertilization can also increase seedling size and abundance of fibrous and lateral roots (Brissette and Carlson, 1992; Dixon et al., 1979).

Root growth potential for shortleaf pine can be significantly impacted by lifting date, storage length, and seedling family (Hallgren and Tauer, 1989). Specifically, seedlings lifted in December and January that were stored for fewer than 28 days had higher root growth potential, survival and growth than those which were stored longer or lifted later. Lifting date is less detrimental than extended storage length if the late-lifted seedlings are quickly planted during an appropriate planting season. Venator (1985) and South and Hallgren (1997) found similar relationships between seedling survival, lifting date, and storage length with earlier lifting being preferred if storage for up to 30 days was necessary, and again with some allowance for late lifting followed by quick outplanting. However, storage was not found to have a strong effect on seedling growth
(Hallgren, 1992). Barnett (1992) suggests similar storage guidelines for containerized stock if they have been removed from trays and boxed.

2.5 Bareroot vs. Containerized Stock

Shortleaf pine seedlings are produced from a variety of seed sources at state-owned and commercial nurseries as either bareroot or containerized stock. Bareroot seedlings are usually cheaper to produce, store, transport, and plant. Unfortunately, they are more susceptible to drought, root damage during the lifting process, and the adverse effects of poor handling during storage and transport than containerized seedlings (Barnett et al., 1986; Gwaze et al., 2006b). Containerized stock with intact plugs containing roots and planting medium tend to be heavier and bulkier for the planting crews and more costly to produce at seedling nurseries, leading to overall higher costs. Containerized stock also tends to be smaller than bareroot stock (Barnett, 1992).

Containerized stock has several attractive differences relative to bareroot stock including more intact root systems that retain fine roots, superior balance in root-to-shoot ratios, and often higher root mass than bareroot seedlings (Barnett, 1992). These attributes often extend the storage and planting window for containerized seedlings and can improve seedling performance, particularly on harsh sites (Barnett, 1992).

Performance of containerized and bareroot shortleaf pine seedlings has been compared by several researchers. Seedlings from six half-sib families in Arkansas were grown as both bareroot and containerized stock and outplanted on the Ouachita National Forest (Barnett and Brissette, 2004). Bareroot seedlings were larger than containerized seedlings at the time of planting but the containerized stock had higher root volume and better root to shoot ratios. Survival was similar between the two stock types after one
growing season but the containerized seedlings had achieved superior height and
diameter growth. The growth of containerized stock continued to exceed that of bareroot
stock when measured at years three, five, and ten. These results contrast several dated
studies reported by Barnett et al. (1986) which found that larger seedlings outperformed
smaller seedlings of both bareroot and containerized stock types. Another comparison
conducted in the Ouachita Mountains found that containerized stock outperformed
bareroot stock on a productive site and bareroot stock performed better on a drier site
(Ruehle et al., 1981). Survival of the containerized stock was poor on both sites but the
poor survival was attributed to the small size of the containerized seedlings, which made
them more susceptible to the dense competition on the site.

A study in Missouri addressed survival and performance by stock type and
seedling age and provides more insight into the effect of seedling size. Gwaze et al.
(2006b) planted 1-0 and 2-0 seedlings of both bareroot and containerized stock in the
Ozark Mountains. The 1-0 containerized stock was grown in containers with 10.3 cubic
inches of soil capacity and 8.25 inches of depth. The 2-0 stock was grown in containers
with 10.5 cubic inches of soil capacity and five inches of depth. The 1-0 and 2-0 bare-
root stock were root pruned to 10 inches and top pruned to 16 inches prior to planting.
After eight growing seasons, 82% of the 2-0 containerized seedlings survived, which was
a 52% improvement over the 2-0 bareroot seedlings. There were no significant
differences in survival between the 1-0 containerized and bareroot seedlings. The poor
survival of the 2-0 bareroot stock in Gwaze et al. (2006b) was theorized to have resulted
from the high levels of root pruning and fibrous root damage that occurred during lifting.
Two year old bareroot stock achieved greater diameter growth than the equivalent
containerized stock, but this was attributed to the greater root collar diameter of the 2-0 bareroot stock at the time of the planting. Differences in height growth between the bareroot and containerized 2-0 stocks were not significant. Diameter and height growth between 1-0 seedlings of both stock types were also not significantly different.

The impacts of container size on seedling survival and growth have not been thoroughly investigated for shortleaf pine but comparisons of performance by container size have been conducted for several other coniferous species. In general, larger containers often provide more space for root development as well as improved water and nutrient availability after transplanting (Aghai et al., 2013; Hsu et al., 1996; Matthes-Sears and Larson, 1999; Dominguez-Lerena et al., 2006; Grossnickle, 2005). Aghai et al. (2013) improved the growth of containerized western larch (Larix occidentalis Nutt.) seedlings grown in simulated xeric site conditions by increasing container depth and volume. Pinto et al. (2011) found that increasing container volume and depth generally improved the growth of ponderosa pine (P. ponderosa Laws. var. ponderosa) during the first growing season on both mesic and xeric sites, although many of the significant differences dissipated over the second growing season. Pinto et al. (2011) also found that container volume did not significant effect seedling survival on xeric or mesic sites.
CHAPTER III
MATERIALS AND METHODS

3.1 Study Site

The study site was located on the NCDA&CS-RSD Umstead Research Farm in Durham County, NC (36° 9'25.75"N, 78°48'54.32"W) (Figure 3.1). Elevations ranged from 434 to 486 feet along a ridge with east and west aspects and less than 10 percent slopes. The site received an average of 47.8 inches of rain annually and had an average growing season of 194 days (Perry, 1996; State Climate Office of North Carolina). Mean temperatures at the site ranged from 37.5° Fahrenheit in January to 77.5° Fahrenheit in July (State Climate Office of North Carolina). The site was located in the Charlotte Slate Belt subsection of the Central Appalachian Piedmont Geological Province less than a mile east of the Southern Triassic Basin (Bailey, 1995; North Carolina Geological Survey, 1985).

The study site contained two soil types. Lignum silt loam dominated the upper portions of the ridge and Helena sandy loam was found on the lower hillslopes (Kirby, 1976). Both soil series are clayey, mixed, thermic Aquic Hapludults within the order Ultisols. Lignum and Helena are both deep and moderately well drained soils which formed under forest vegetation, although the parent material from which the residuum originated differs. Lignum soils result from weathered volcanic slate while Helena soils weather under igneous granodiorite (Kirby, 1976). Field measurements revealed a site
index (base age 50) for shortleaf pine for these soils of approximately 63 feet. Helena sandy loam has a low-hazard score for littleleaf disease and Lignum silt loam scores in the upper end of moderate-hazard (Campbell and Copeland, 1954). Several large boulders, areas of exposed rock, and highly eroded areas were found across the study site. The site also contained evidence of at least one period of mixed agricultural use. Man-made piles of field stones and remnant raised planting beds along and at the base of the hillslopes suggested past tilling and row cropping. Barbed wire, old fence posts as well as the presence of several large overstory oaks and hickories suggested prior woodland grazing on the rockier upland portions of the site.

Figure 3.1 Location of the study site on the Umstead Research Station in relation to the Central Appalachian Piedmont Region
The forest cover of the study site prior to harvest consisted of a naturally-regenerated mixed upland hardwood-pine stand with a multi-cohort, mixed species structure. The overstory was dominated by oak and hickory species including white oak (*Quercus alba* L.), northern red oak (*Q. rubra* L.), southern red oak (*Q. falcata* Michx.), post oak (*Q. stallata* Wangenh), black oak (*Q. velutina* Lam.), willow oak (*Q. phellos* L.), mockernut hickory (*Carya tomentosa* (Poir.) Nutt.), pignut hickory (*C. glabra* (Mill.) sweet), and red hickory (*C. ovalis* (Wangenh.) Sarg.) Species including yellow poplar (*Liriodendron tulipifera* L.), winged elm (*Ulmus alata* Michx.) red maple (*Acer rubrum* L.), sweetgum (*Liquidambar styraciflua* L.), Virginia pine (*Pinus virginiana* Mill.), loblolly pine (*P. taeda* L.), shortleaf pine (*P. echinata* Mill.) and eastern redcedar (*Juniperus virginiana*) occupied dominant and co-dominant overstory positions in limited portions of the stand. A majority of the co-dominant stems became established following the most recent agricultural abandonment in the 1940s. Several of the dominant overstory oaks and hickories became established as long ago as the late 1880s.

The midstory cohort contained a minor component of American beech (*Fagus grandifolia* Ehrh.) but was dominated by winged elm, hickory, American hornbean (*Carpinus caroliniana* Walter), eastern hophornbeam (*Ostrya virginiana* (Mill.) K.), blackjack oak (*Q. marilandica* Muenchh.), American holly (*Ilex opaca* Aiton), and eastern redcedar. Advance reproduction, characterized as seedlings or saplings that develop or are present in the understory prior to the death of overstory trees (Helms, 1998), was comprised mostly of winged elm, hickory species, eastern redcedar, American holly and a very limited quantity of white and post oaks. Herbaceous groundcover was sparse prior to the harvest. A non-exhaustive survey of understory plants revealed the

3.2 Treatments and Implementation

The study site contained twenty-eight 0.33-acre (67.98-foot radius) circular residual overstory basal area treatment plots (Figure 3.2). The plots were organized into seven replicated blocks arranged across the site to account for variability in slope, slope position, aspect, and soil type. Each block of four residual overstory basal area (RBA) treatment plots contained one randomly assigned replicate of each of the four treatments retaining zero (RBA0), 15 (RBA15), 30 (RBA30) and 45 (RBA45) square feet basal area per acre following harvest.
The overstory trees necessary to obtain the residual basal area target within the treatment plots were selected based on species, form, size and visual assessment of health. Tree location was also considered to ensure that basal area was evenly distributed across each plot. Oak and hickory were targeted for retention due to their typical association with shortleaf pine in Central Appalachian Piedmont ecological communities (Schafale, 2013). Limited numbers of winged elm, red maple, yellow poplar, American beech, loblolly pine, eastern redcedar, and sweetgum were retained to meet residual overstory basal area targets and ensure appropriate overstory distribution across the treatment plots. Each treatment plot was commercially harvested to its assigned residual basal area target in the summer and early fall of 2012. The site was whole-tree harvested
using a wheeled feller-buncher and skidder. The slash and tops were piled outside of the study area for later commercial utilization. A broadcast burn was completed in November, 2012 to prepare the site for planting.

A 0.10-acre (37.2 foot radius) circular seedling measurement plot was established at plot center of each treatment plot (Figure 3.3). Three, one year-old (1-0) shortleaf pine stock types were underplanted within each of the seedling measurement plots between January 19th and February 8th, 2013. The three stock types included bareroot, containerized seedlings with small plugs and containerized seedlings with large plugs. Bareroot seedlings were grown in Crimora, Virginia using an orchard mix of seed originating from a shortleaf pine seed orchard in Providence Forge, Virginia. The containerized seedlings with small plugs were produced in Moultrie, Georgia using an orchard mix of improved shortleaf pine seed originating from the piedmont region of North Carolina. The containers measured approximately 1.6 inches in diameter and 3.5 inches in depth to facilitate planting in rocky soils. The containerized seedlings with large plugs were grown in Goldsboro, NC using seed from an orchard mix of improved shortleaf pine seed of North Carolina origin. Container size was roughly 1.5 inches in diameter and 4.75 inches in depth.
The rocky soils of the study site prevented planting at a uniform spacing but the seedlings were distributed as evenly as possible throughout the 0.10-acre seedling measurement plots (Figure 3.3). The seedlings were planted in lines which originated from plot center and terminated at the outer edge of the seedling measurement plot. Each line consisted of two to four seedlings of the same stock type and the lines alternated by stock type around the plot. 36 each of the bareroot and small plugged seedlings were established in each plot. Limited seedling availability permitted the establishment of only 20 to 22 large plugged seedlings per plot. Proper seedling storage, handling, and planting practices were followed during the reforestation process (Barnett et al., 1986).
3.3 Measurements

Initial seedling groundline diameters (GLD) and heights were measured and recorded in February, 2013. GLD was measured to an accuracy of 0.01 inch with a single measurement using a digital caliper. Height was measured to an accuracy of 0.01 feet using an engineer scale in units of 10ths of feet. Height measurements were taken on the uphill side of the underplanted seedling and measured to the tallest dominant leader. Seedlings were assigned unique identification numbers and tagged with aluminum tags to facilitate future identification. A colored pin flag was also placed next to each seedling to facilitate future location and measurement.

First year seedling survival, GLD and height were collected in September, 2013. Seedlings were recorded as dead if they were entirely brown and showed no signs of basal sprouting. Topkilled trees with basal sprouting were considered alive, but were removed from growth analysis. Measurements were taken in January and February of 2015 to obtain groundline diameter and height after the second growing season. Initial height and GLD were subtracted from year-two measurements to obtain height and groundline diameter growth after two growing seasons.

Site visits in October, 2013 revealed high levels of sawfly damage to the seedlings. Additionally, unusually severe deer browse was noticed during a site visit following an early February, 2014 snowstorm that resulted in approximately seven inches of snow covering the site for several days. Mammal browse and sawfly damage were assessed in late February, 2014. Field crews visited each seedling and recorded whether it had been browsed and/or defoliated. Residual overstory trees were also inventoried in the
summer and winter of 2013 and 2014 to account for basal area reductions due to wind and ice damage and general mortality.

3.4 Statistical Analysis

The experimental design for this study originally consisted of a randomized complete block design with a 4x3 factorial with the intention of using the four residual overstory basal area levels and three stock types, both expressed as categorical variables, as the primary main effects. The response variables included plot-level mean seedling survival, seedling height growth, and groundline diameter growth expressed as continuous numeric variables. However, wind and ice damage to the overstory during the summer and winter of 2013 placed several residual basal area plots more than five square feet outside of their assigned basal area level. Therefore, plot-level residual overstory basal area expressed as a continuous numeric variable was used rather than the four overstory basal area category levels for the year-two seedling growth analysis.

Since deer and sawfly damage can negatively impact seedling survival (Lawson, 1990) and growth (Cain and Shelton, 2002; Kabrick et al. 2011, Little and Mohr, 1961; Wilson and Averill, 1978), survival analysis was only performed on data collected following the first growing season, before the biotic damage occurred. Additionally, plot-level mean height and groundline diameter growth values derived from fewer than five living seedlings undamaged by browsing or sawfly were excluded from the year-two growth analysis. Plot-level percent deer browse and sawfly damage were also added to the analysis as response variables.

The response variables were analyzed for residual overstory basal area and stock type treatment differences through analysis of covariance (ANCOVA) using a general
linear models approach. This design allowed for statistical control of the potential confounding variables associated with this study. A critical value of $\alpha=0.10$ was used to determine statistical significance. Tukey’s Honest Significant Difference (HSD) was conducted as a post-hoc test to compare means when significant differences were detected within the stock type treatments. Linear regression was used to explore the relationship between residual overstory basal area and height and GLD growth for each stock type. Main effects, covariates, and interactions were included in the model but removed from the analysis through backwards elimination if they were found to lack significant effect. Statistical analyses were performed in SAS/STAT® Enterprise Guide 7.1 software (SAS Institute Inc., Cary, NC).
CHAPTER IV
RESULTS

4.1 Initial Seedling Size

There were significant differences in mean initial seedling height and GLD by stock type (Table 4.1). Bareroot seedlings had the tallest mean heights (0.80 feet) and GLD (0.15 inches) at the time of planting. The containerized seedlings with small plugs were the second largest in both height (0.79 feet) and GLD (0.14 inches) but were not significantly smaller than bareroot seedlings (Table 4.2). Large plug seedlings had significantly smaller initial mean heights (0.40 feet) and GLD (0.11 inches) than bareroot and small plug seedlings (Table 4.2). There was no significant residual overstory basal area treatment effect at the time of planting (Table 4.1).

Table 4.1 F-tests for main effects stock type and residual overstory basal area (RBA) on initial seedling height and GLD

<table>
<thead>
<tr>
<th>Variable</th>
<th>Source</th>
<th>DF</th>
<th>Type III SS</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>Block</td>
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<td>0.01</td>
<td>0.00</td>
<td>0.41</td>
<td>0.8702</td>
</tr>
<tr>
<td></td>
<td>Stock Type</td>
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<td>0.91</td>
<td>299.64</td>
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</tr>
<tr>
<td></td>
<td>RBA</td>
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<td>0.00</td>
<td>0.21</td>
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</tr>
<tr>
<td></td>
<td>Error</td>
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<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GLD</td>
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<td>0.00</td>
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<tr>
<td></td>
<td>Error</td>
<td>43</td>
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<td></td>
</tr>
</tbody>
</table>

Significant P-values indicated in bold.
Table 4.2 Tukey-Kramer adjustment for multiple comparisons of LS means for the effect of Stock Type on initial seedling height and GLD

<table>
<thead>
<tr>
<th>Stock Type</th>
<th>Initial Seedling Height (feet)</th>
<th>Initial Seedling GLD (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bareroot</td>
<td>0.80(^a)</td>
<td>0.15(^a)</td>
</tr>
<tr>
<td>Small Plug</td>
<td>0.79(^a)</td>
<td>0.14(^a)</td>
</tr>
<tr>
<td>Large Plug</td>
<td>0.40(^b)</td>
<td>0.11(^b)</td>
</tr>
</tbody>
</table>

Levels not connected by the same letter are significantly different.

4.2 Residual Overstory Basal Area

Most treatment plots maintained or increased in overstory basal area during the first and second growing seasons. Residual tree growth even caused a few plots to exceed their original basal area levels after the second growing season. However, several plots experienced a decline in overstory basal area following wind and ice damage in summer 2013 and winter 2013/14, respectively. Damage ranged from approximately 3\% to 20\% reduction in overstory basal area (Table 4.3). Most damaged plots began to recover lost basal area through residual tree growth during the second growing season, but a few plots continued to lose basal area.
Table 4.3  Overstory basal area at the time of planting (RBA_0) and following the first (RBA_1) and second (RBA_2) growing seasons by block and treatment

<table>
<thead>
<tr>
<th>Block</th>
<th>Treatment</th>
<th>RBA_0</th>
<th>RBA_1</th>
<th>RBA_2</th>
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<tr>
<td>1</td>
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<td>0</td>
<td>0</td>
<td>0</td>
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<td>43</td>
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<td>7</td>
<td>BA45</td>
<td>45</td>
<td>46</td>
<td>46</td>
</tr>
</tbody>
</table>

Plots that received overstory damage from wind and ice are indicated in bold.
4.3 Survival

Stock type and overstory basal area had significant effects on seedling survival over one growing season (Table 4.4), with significant differences in survival among all three stock types (Table 4.5). Large plug seedlings had the highest survival (99.12%), followed by the small plug seedlings (91.38%) and the bareroot seedlings (64.85%). Survival was poorest in the clearcut plots for all three stock types, although basal area only significantly impacted survival for the small plug and bareroot seedlings (Table 4.6). Initial seedling height (p=0.6576) and initial GLD (p=0.7069) did not significantly affect seedling survival.

Table 4.4  F-tests for main effects stock type and residual overstory basal area on seedling survival

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Type III SS</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
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<td>1183.90</td>
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</tbody>
</table>

Significant P-values indicated in bold.

Table 4.5  Tukey-Kramer adjustment for multiple comparisons of LS means for the effect of Stock Type on percent mean seedling survival

<table>
<thead>
<tr>
<th>Stock Type</th>
<th>Mean Survival (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Plug</td>
<td>99.12(^a)</td>
</tr>
<tr>
<td>Small Plug</td>
<td>91.38(^b)</td>
</tr>
<tr>
<td>Bareroot</td>
<td>64.85(^c)</td>
</tr>
</tbody>
</table>

Levels not connected by the same letter are significantly different.
Simple linear regression was used to examine the relationship between mean seedling survival and residual overstory basal area (Table 4.6). Significant regression equations were found for the small plug and bareroot stock types (Figure 4.1). For small plug seedlings, predicted survival was equal to 86.9833+0.19335*(RBA). Mean survival for small plug seedlings increased an average of 2.9% for each 15 square feet of additional residual overstory basal area. Predicted survival for bareroot seedlings is equal to 55.97692+0.39*(RBA). Mean seedling survival for bareroot seedlings increased by an average of 5.9% for each 15 square feet of additional residual overstory basal area. Residual basal area did not significantly affect the survival of containerized seedlings with large plugs (Table 4.6).

Table 4.6  Effects of overstory basal area on percent seedling survival after one growing season by stock type

<table>
<thead>
<tr>
<th>Stock Type</th>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Plug</td>
<td>Model</td>
<td>1</td>
<td>7.21</td>
<td>7.21</td>
<td>1.31</td>
<td>0.2636</td>
</tr>
<tr>
<td>(R²=0.0478)</td>
<td>Error</td>
<td>26</td>
<td>143.57</td>
<td>5.52</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Corrected Total</td>
<td>27</td>
<td>150.78</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small Plug</td>
<td>Model</td>
<td>1</td>
<td>307.74</td>
<td>307.74</td>
<td>5.22</td>
<td><strong>0.0308</strong></td>
</tr>
<tr>
<td>(R²=0.1671)</td>
<td>Error</td>
<td>26</td>
<td>1533.91</td>
<td>59.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Corrected Total</td>
<td>27</td>
<td>1841.65</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bareroot</td>
<td>Model</td>
<td>1</td>
<td>1252.07</td>
<td>1252.07</td>
<td>3.84</td>
<td><strong>0.0608</strong></td>
</tr>
<tr>
<td>(R²=0.1287)</td>
<td>Error</td>
<td>26</td>
<td>8475.48</td>
<td>325.98</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Corrected Total</td>
<td>27</td>
<td>9727.55</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Significant P-values indicated in bold.
4.4 Growth

4.4.1 Height growth

Stock type and overstory basal area had significant effects on seedling height growth over two growing seasons (Table 4.7). Large plug seedlings averaged 1.62 feet of height growth, which was significantly greater than the small plug (1.07 feet) and bareroot (0.91 feet) seedlings (Table 4.8). Differences in two-year height growth between the small plug and bareroot seedling were not significant.

Linear regression was used to examine the relationship between mean seedling height growth and residual overstory basal area (Table 4.9). Significant regression equations were found for the large plug and small plug stock types (Figure 4.2). Predicted
seedling height growth over two growing seasons for large plug stock was equal to 
2.06450-0.01859*(RBA). Mean seedling height growth for large plug seedlings 
decreased by an average of 0.29 feet for each 15 square feet of additional residual 
overstory basal area. Predicted mean height growth for small plug seedlings was equal to 
1.42005-0.01367*(RBA). Mean seedling height growth for small plug seedlings 
decreased on average by 0.21 feet for each 15 square feet of additional residual overstory 
basal area. Overstory basal area did not have a significant effect on bareroot seedling 
height growth (Table 4.9). Initial seedling height (p=0.8324) and initial GLD (p=0.7400) 
did not have a significant effect on seedling height growth.

Table 4.7  F-tests for main effects residual overstory basal area (RBA) and stock type 
on seedling height and GLD growth after two growing seasons

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Type III SS</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RBA</td>
<td>1</td>
<td>2.20</td>
<td>2.20</td>
<td>22.23</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Block</td>
<td>6</td>
<td>1.21</td>
<td>0.20</td>
<td>2.05</td>
<td>0.0823</td>
</tr>
<tr>
<td>Stock type</td>
<td>2</td>
<td>4.66</td>
<td>2.33</td>
<td>23.57</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>RBA*Block</td>
<td>6</td>
<td>1.66</td>
<td>0.28</td>
<td>2.8</td>
<td>0.0232</td>
</tr>
<tr>
<td>Error</td>
<td>39</td>
<td>3.86</td>
<td>0.10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GLD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OBA2</td>
<td>1</td>
<td>0.17</td>
<td>0.17</td>
<td>47.97</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Block</td>
<td>6</td>
<td>0.13</td>
<td>0.02</td>
<td>6.12</td>
<td>0.0002</td>
</tr>
<tr>
<td>Stock Type</td>
<td>2</td>
<td>0.12</td>
<td>0.06</td>
<td>16.99</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>RBA*Block</td>
<td>6</td>
<td>0.11</td>
<td>0.02</td>
<td>4.96</td>
<td>0.0008</td>
</tr>
<tr>
<td>RBA*Stock Type</td>
<td>2</td>
<td>0.02</td>
<td>0.01</td>
<td>3.12</td>
<td>0.0562</td>
</tr>
<tr>
<td>Error</td>
<td>37</td>
<td>0.13</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Significant P-values indicated in bold.
Table 4.8  
Tukey-Kramer adjustment for multiple comparisons of LS means for the effect of Stock Type on seedling height and GLD growth after two growing seasons

<table>
<thead>
<tr>
<th>Stock Type</th>
<th>Height Growth (feet)</th>
<th>GLD growth (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Plug</td>
<td>1.62&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.38&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Small Plug</td>
<td>1.07&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.32&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Bareroot</td>
<td>0.91&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.23&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Levels not connected by the same letter are significantly different.

Table 4.9  
Effects of residual overstory basal area on seedling height and GLD growth after two growing season by stock type

<table>
<thead>
<tr>
<th>Stock Type</th>
<th>Variable</th>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Model</td>
<td>1</td>
<td>1.70</td>
<td>1.70</td>
<td>14.03</td>
<td>0.0016</td>
</tr>
<tr>
<td>Large Plug</td>
<td>Height</td>
<td>Error</td>
<td>17</td>
<td>2.07</td>
<td>0.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>18</td>
<td>3.77</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GLD</td>
<td>Model</td>
<td>1</td>
<td>0.14</td>
<td>0.14</td>
<td>25.27</td>
<td>0.0001</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error</td>
<td>17</td>
<td>0.09</td>
<td>0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>18</td>
<td>0.23</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small Plug</td>
<td>Height</td>
<td>Model</td>
<td>1</td>
<td>0.85</td>
<td>0.85</td>
<td>6.18</td>
<td>0.0236</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error</td>
<td>17</td>
<td>2.34</td>
<td>0.14</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>18</td>
<td>3.19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GLD</td>
<td>Model</td>
<td>1</td>
<td>0.11</td>
<td>0.11</td>
<td>12.66</td>
<td>0.0024</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error</td>
<td>17</td>
<td>0.14</td>
<td>0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>18</td>
<td>0.25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bareroot</td>
<td>Height</td>
<td>Model</td>
<td>1</td>
<td>0.31</td>
<td>0.31</td>
<td>2.66</td>
<td>0.1235</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error</td>
<td>15</td>
<td>1.73</td>
<td>0.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>16</td>
<td>2.03</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GLD</td>
<td>Model</td>
<td>1</td>
<td>0.01</td>
<td>0.01</td>
<td>2.3</td>
<td>0.1504</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error</td>
<td>15</td>
<td>0.07</td>
<td>0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total</td>
<td>16</td>
<td>0.08</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Significant P-values indicated in bold.

39
There was a significant overstory basal area x block interaction on seedling height growth after two growing seasons for large plug, small plug, and bareroot stock types. This interaction was strongly influenced by the zero square foot plot of block five. This plot had particularly high height and GLD growth. The removal of the plot from the analysis eliminated the significance of the interaction without changing the results, although all analysis has been reported with the block still included.

4.4.2 Groundline Diameter Growth

Stock type and overstory basal area also had significant effects on seedling GLD growth over two growing seasons (Table 4.7). There were significant differences in GLD growth between all three stock types (Table 4.8). Large plug seedlings averaged 0.39
inches of GLD growth followed by the small plug (0.32 inches) and the bareroot seedlings (0.23 inches).

Linear regression was used to examine the relationship between mean seedling GLD growth and residual overstory basal area (Table 4.9). Significant regression equations were found for the large plug and small plug stock types (Figure 4.3). For large plug seedlings, predicted seedling GLD growth over two growing seasons was equal to $0.50820 - 0.00532 \times (RBA)$. Mean seedling height growth for large plug seedlings decreased on average by 0.08 inches for each 15 square feet of additional residual overstory basal area. The predicted percent survival for small plug seedlings was equal to $0.44172 - 0.00487 \times (RBA)$. Mean seedling GLD growth for small plug seedlings decreased by an average of 0.07 inches for each 15 square feet of additional residual overstory basal area. Overstory basal area did not have a significant effect on bareroot seedling GLD growth (Table 4.9). Initial seedling height ($p=0.9193$) and initial GLD ($p=0.5813$) did not have significant effects on underplanted seedling GLD growth.

The absence of a significant overstory basal area effect on bareroot seedling GLD growth contributed to a significant overstory basal area x stock type interaction ($P=0.0562$) (Table 4.7). Similarly to the height growth analysis, the significant overstory basal area x block interaction ($P=0.0008$) was influenced heavily by the zero square foot plot of block five, but again its removal did not impact the results of the analysis.
4.5 Deer and Sawfly Damage

Stock type had a significant effect on deer browse (Table 4.10). The small plug seedlings were the most heavily damaged with 40.4% of the seedlings browsed, followed closely by the large plug seedlings (39.9%) (Table 4.11). The difference in mean browse damage between the large plug and small plug seedlings was not significant. Bareroot seedlings’ browse rate of 26.0% was significantly lower than the large plug and small plug seedlings.
Table 4.10  Effects of residual overstory basal area on percent of seedlings browsed by deer or damaged by sawfly after one growing season by stock type

<table>
<thead>
<tr>
<th>Variable</th>
<th>Source</th>
<th>DF</th>
<th>Type III SS</th>
<th>Mean Square</th>
<th>F Value</th>
<th>Pr &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deer Browse</td>
<td>Block</td>
<td>6</td>
<td>4665.87</td>
<td>777.65</td>
<td>3.18</td>
<td>0.0083</td>
</tr>
<tr>
<td></td>
<td>Stock Type</td>
<td>2</td>
<td>3726.00</td>
<td>1863.00</td>
<td>7.62</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>RBA</td>
<td>1</td>
<td>1129.08</td>
<td>1129.08</td>
<td>4.62</td>
<td>0.0352</td>
</tr>
<tr>
<td></td>
<td>RBA*Block</td>
<td>6</td>
<td>3300.02</td>
<td>550.00</td>
<td>2.25</td>
<td>0.0487</td>
</tr>
<tr>
<td></td>
<td>Error</td>
<td>68</td>
<td>16631.06</td>
<td>244.57</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sawfly Damage</td>
<td>Block</td>
<td>6</td>
<td>4959.95</td>
<td>826.66</td>
<td>2.74</td>
<td>0.0187</td>
</tr>
<tr>
<td></td>
<td>Stock Type</td>
<td>2</td>
<td>1155.38</td>
<td>577.69</td>
<td>1.91</td>
<td>0.1551</td>
</tr>
<tr>
<td></td>
<td>RBA</td>
<td>1</td>
<td>28.70</td>
<td>28.70</td>
<td>0.09</td>
<td>0.7588</td>
</tr>
<tr>
<td></td>
<td>Error</td>
<td>74</td>
<td>22366.53</td>
<td>302.25</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Significant P-values indicated in bold.

Table 4.11  Tukey-Kramer adjustment for multiple comparisons of LS means for the effect of Stock Type on deer browse after one growing season.

<table>
<thead>
<tr>
<th>Stock Type</th>
<th>Mean Deer Browse (percent)</th>
<th>Mean Sawfly Damage (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large Plug</td>
<td>39.87&lt;sup&gt;a&lt;/sup&gt;</td>
<td>31.38&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Small Plug</td>
<td>40.36&lt;sup&gt;a&lt;/sup&gt;</td>
<td>35.86&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Bareroot</td>
<td>25.99&lt;sup&gt;b&lt;/sup&gt;</td>
<td>40.46&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Levels not connected by the same letter are significantly different.

Residual overstory basal area as well as a residual basal area x block interaction appeared to have significant effects on percent deer browse (Table 4.10). However, the significance of residual overstory basal area and the interaction disappeared when the stock types were analyzed individually (Table 4.12). Percent deer browse nominally increased with increasing residual overstory basal area for all three stock types but the linear relationship was not significant for any of the stock types (Table 4.12).
Neither stock type nor residual overstory basal area significantly affected percent sawfly damage after the first growing season (Table 4.10). The bareroot stock had the highest rate of sawfly infestation (40.46%) followed by the small plug (35.86%) and the large plug (31.38%) seedlings (Table 4.11).
5.1 Survival and Growth

5.1.1 Overstory Basal Area

Retaining as little as 15 square feet of residual overstory density increased underplanted seedling survival on this adverse Central Appalachian Piedmont site. Mean survival was poorest in the clearcut plots for all three stock types but gradually improved with increasing overstory basal area. Overstory basal area had the opposite effect on underplanted seedling growth and led to reductions in both height and GLD growth, although seedling growth under the clearcut and seed tree treatments was actually very similar. The growth reductions were therefore most severe under the low and moderate shelterwood levels. While the relationship between overstory density and underplanted seedling growth was only significant for the containerized stock, the bareroot seedlings also experienced marginal declines in growth as residual overstory basal area increased.

The positive influence that overstory basal area had on early seedling survival is in line with the findings of Kabrick et al. (2011). These results contrast previous underplanting studies where overstory basal area either did not impact (Guldin and Heath 2001) or negatively impacted seedling survival (Jensen et al., 2007, Jensen and Gwaze, 2007). One reason for the different findings may be related to the order in which silvicultural treatments were implemented. This study and Kabrick et al. (2007)
underplanted seedlings beneath already established overstory treatments. Guldin and Heath (2001), Jensen et al. (2007), and Jensen and Gwaze (2007) underplanted seedlings prior to manipulating overstory basal area. Beyond these differences, Guldin and Heath (2001) established their study on a north-facing slope, which presumably would have been more mesic with better growing conditions than the summit and shoulder positions used by Kabrick et al. (2011) or the east and west-facings aspects of this study site, which may also have contributed to differences in survival.

The positive relationship between overstory basal area and small plug and bareroot seedling survival is attributed to overstory and understory competition as well as the moderation of site harshness created by different levels of overstory density. High levels of herbaceous competition were observed in the clearcut plots but herbaceous competition decreased through the seed tree and lower shelterwood density levels and was sparse under the moderate shelterwood. The ability of overstory trees to control competing vegetation in the understory is similar to what has been observed in shelterwood regeneration harvests aimed at naturally regenerating shortleaf pine (Baker, 1992). As competition control can improve shortleaf pine seedling survival and growth (Amishev and Fox, 2006; Kushla, 2009; Yeiser, 1992; Yeiser and Barnett, 1991), the shade provided by the residual overstory may have positively contributed to seedling survival through controlling competing vegetation. The competition control effect may also partially explain why growth in plots with seed tree levels of overstory density was less variable and sometimes higher than in clearcut plots.

In addition to controlling competing vegetation, the overstory trees in this study would presumably have moderated site harshness, further contributing to seedling
survival. Fully exposed clearcut sites generally have harsher microclimatic conditions including higher soil and air temperatures near the ground level compared to sites with residual overstory (Guldin and Barnett, 2004). The harsh microclimatic conditions and the abundant herbaceous competition in the clearcut plots, coupled with the inherently harsh conditions of this site, are suspected to have caused the comparatively high levels of seedling mortality in clearcut plots. This likely resulted in the significant effect of overstory basal area on underplanted seedling survival.

The negative effect of residual overstory stocking on underplanted seedling growth is in agreement with the findings of previous studies in which shortleaf pine seedlings have been underplanted beneath hardwood overstories (Guldin and Heath, 2001; Jensen and Gwaze, 2007; Jensen et al., 2007; Kabrick et al., 2011). The reductions in growth resulting from residual overstory basal area are attributed to the shading caused by the residual overstory trees. While shortleaf pine is perhaps slightly more shade tolerant than other southern pine species, it is still considered shade intolerant and generally grows best under full sun (Masters, 2007; Lawson, 1990; Guldin, 1986). Belowground competition from both the root systems of the overstory trees as well as the woody and herbaceous competition in the plots may also have reduced underplanted seedling growth by competing for moisture and nutrients (Smith et al., 1996).

Further examination of the data from this study shows that mean seedling growth under seed tree stocking levels are often similar to, and in some cases exceeds that of the clearcut plots. Like the survival results, this analysis suggests that the herbaceous and woody competition control and site-moderating benefits provided by as little as fifteen square feet of residual overstory basal area can provide early benefits to seedling growth.
on harsh North Carolina Piedmont sites. However, the benefits are likely short term as the residual overstory trees on this site are continuing to grow and will eventually reach density levels under which this analysis reveals that seedling growth will be suppressed. Further research should investigate how an increasing overstory density impacts the underplanted trees as they reach sapling size.

### 5.1.2 Stock Type

Containerized seedlings had significantly better survival and growth compared to bareroot stock on this adverse North Carolina Piedmont site. There were also significant differences in both survival and growth between the two containerized stock types. However, the differences in survival between containerized stock are likely not operationally significant as both stock types achieved over 90% mean survival. The bareroot stock had poor survival on this site with several plots failing to achieve 50% survival over the first growing season. Additionally, the bareroot seedlings that did survive had less growth compared to the two containerized stock types.

The higher survival rates and superior growth of the containerized seedlings compared to bareroot stock are similar to the findings of Barnett and Brissette (2004) after ten growing seasons. However, Brissette and Barnett (1989) did not find significant differences by stock type after the first growing season of the same study. The results of this North Carolina study also contrast the results of Gwaze et al. (2006b) where there were no significant differences in survival by stock type between 1-0 seedlings after eight growing seasons and 1-0 bareroot seedlings had marginally better growth than containerized seedlings. The results of this study also differ from Ruehle et al. (1981)
where bareroot stock had superior survival and growth than containerized seedlings on a marginal site in Arkansas after two growing seasons.

Differences in site preparation techniques employed prior to reforestation may explain why this young study revealed significant stock type differences in survival and growth while Brissette and Barnett (1989) and Gwaze et al. (2006b) found only marginal and insignificant differences. This North Carolina site received very little site preparation consisting only of a low-intensity, and largely unsuccessful, prescribed burn. This is in contrast to Brissette and Barnett (1989) who established seedlings in a ripped clearcut and Gwaze et al. (2006b) who planted seedlings in a ploughed and disked former nursery bed. Ripping can improve early survival and growth of outplanted bareroot seedlings on adverse sites (Berry, 1979; Gwaze et al., 2006a; McClure, 1984) and may have masked early stock type differences from Brissette and Barnett (1989) and Gwaze et al. (2006b). Significant differences between the two stock types established in Brissette and Barnett (1989) after ten growing seasons as reported in Barnett and Brissette (2004) may show the diminishing of the benefits of site preparation, which would be in line with Gwaze et al. (2006a) who found that the benefits of ripping can be short term.

Previous studies have also indicated that family and stock type can interact to lead some families to perform best as bareroot stock and vice versa (Brissette and Barnett, 1989; Gwaze et al., 2006b). Such interactions influenced the seedling growth results of Brissette and Barnett (1989) and seedling survival and growth for Gwaze et al. (2006). Local climatic conditions at the seed source can also influence seedling performance at the outplanted site (Schmidtling, 1995). While this study was not designed to test for such interaction or seed source differences, they do not appear to have had meaningful
influences on the results of this study. Brissette and Barnett (1989), Barnett and Brissette (2004) and Gwaze et al. (2006b) compared known half-sib families that had been grown as both bareroot and containerized stock whereas the three stock types used in this study were produced using orchard mixes that randomly combined many families. The random mixture of seed used to produce the seedlings in this study may have masked the appearance of any meaningful stock type x family interactions. Additionally, the buffering caused by the mixture of families and the fact that all three orchard mixes were comprised of families originating from areas that meet Schmidtling’s (2001) seed transfer guidelines would likely have moderated the effect of seed source on the survival analysis. That being said, the design of this study prevents the formal rejection of a family x stock type interaction or analysis of the effects of seed source.

The improved performance in both survival and growth of the containerized seedlings in this study is attributed to the more intact root systems, greater root mass, and more balanced shoot-to-root ratio that containerized seedlings often have compared to bareroot seedlings (Barnett, 1992; Barnett and Brissette, 2004). The differences in survival between the two containerized stocks are attributed to the higher volume and greater depth of the large plug. Larger containers often provide more space for root development as well as improved water and nutrient availability after transplanting (Aghai et al., 2013; Hsu et al., 1996; Matthes-Sears and Larson, 1999; Dominguez-Lerena et al., 2006; Grossnickle, 2005). These characteristics could have improved survival on this harsh planting site. Planting depth, which can influence early seedling survival and growth of bareroot shortleaf pine seedlings (South et al., 2012), may also have contributed. Specifically, the additional 1.25 inches of depth of the large plug
compared to the small plug stock naturally results in a deeper planting depth and may have given the large plug seedlings an advantage on this site.

Perhaps most difficult to explain are the differences between the results of this North Carolina study and those of Ruehle et al. (1981) on a harsh Arkansas site. There were similarities in site preparation between the two studies and both used orchard mixes to produce seedlings. However, the containerized seedlings used in Ruehle et al. (1981) were very small and produced in container cells with lower volume than the seedlings used in this study. Additionally, Ruehle et al. (1981) outplanted their containerized seedlings in October, thus exposing the small seedlings to winter weather. Shortleaf pine growth can be reduced if subjected to temperatures below approximately 10° Fahrenheit after the trees begin active growth (Stevenson et al., 2012). The small initial size of the seedlings at the time of outplanting was likely the primary driver of their poor survival and growth, as was speculated by Ruehle et al. (1981) and further supported by studies relating initial seedling size to first year performance reported by Barnette et al. (1986). However, low winter temperatures following outplanting (Stevenson, et al. 2012), and the low container volume (Aghai et al., 2013; Pinto et al., 2012) may have also contributed to the poor performance of Ruehle et al.’s (1981) containerized seedlings and ultimately the differences in results between these two studies.

5.2 Deer Browse and Sawfly Damage

Deer browsing was slightly influenced by residual overstory basal area, although the relationship is very weak and insignificant when stock types are analyzed separately. Deer browse was also concentrated more on the containerized stock, which were the tallest seedlings after one growing season, than the shorter bareroot seedlings.
A potential explanation for both of these findings is greater snow interception in plots with high residual overstory stocking. Snow can accumulate in forest canopies and sublimate back into the atmosphere before ever reaching the forest floor, resulting in slightly lower snow accumulation in plots with higher canopy cover (Essery et al., 2003; Leonard, 1961; Penn et al., 2012; Schomaker 1968; Varhola et al., 2010). Lower snow accumulation under the plots with higher overstory stocking levels may have therefore exposed more shortleaf pine seedlings to deer searching for food over a multi-day period of snow cover during the winter of 2013/14. The higher rates of browse on the two tallest stock types would further support this speculation. Finally, the Umstead Research Station experienced a heavy acorn crop during the fall of 2013. As this study retained primarily healthy and mature oak and hickory species in the overstory, the deer may simply have returned to a known food source during the winter storm but settled for browsing on shortleaf pine seedlings.

Sawfly damage was not influenced by overstory basal area or stock type. However, the conditions of this site may have predisposed it to such a heavy infestation. Sawfly damage is common amongst pines usually less than 15 feet tall that are growing in stressful conditions caused by high amounts of competing vegetation and poor soils (Wilson and Averill, 1997). Additionally, they commonly infest pines growing along the edges of hardwood forests (Wilson and Averill, 1997). Such conditions nearly perfectly describe this study site so it is not surprising that this site experienced damage considering a localized outbreak of redheaded sawfly was experienced on several recently planted sites across the Umstead Research Station during the fall of 2013.
Underplanting seedlings beneath a residual hardwood overstory appears to be a suitable method of establishing shortleaf pine. The observed suppression of competing vegetation as well as the likely microclimatic moderation provided by low levels of overstory basal area likely improved underplanted seedling survival over one growing season without negatively impacting early growth. The improvements in survival were particularly noticeable for bareroot seedlings, which struggled to survive in clearcut plots. Retention of more than approximately 20 square feet of overstory results in noticeable reductions of both height and GLD growth. However, landowners with objectives that place more emphasis on aesthetics, the retention of mast-producing species in order to meet wildlife objectives, or target specific species compositions and densities in order to meet ecological objectives might find the growth rates under the higher residual overstory basal areas to be acceptable. They may also prefer to use residual overstory basal area instead of herbicides to suppress competing vegetation. Landowner objectives should determine the threshold at which survival, aesthetic, wildlife, or ecological benefits no longer outweigh growth reduction of the underplanted seedlings.

The results of this study suggest that containerized shortleaf pine outperforms bareroot stock on adverse sites in the Central Appalachian Piedmont that have received minimal site preparation. The North Carolina orchard mixes of shortleaf pine seed used
by the commercial seedling producers to grow containerized stock for this study appear to perform very well. These seedlings may be ordered for reforestation projects in the Central Appalachian Piedmont. Additionally, producing these containerized seedlings with larger and preferably deeper containers may provide further improvements in seedling survival and growth on adverse sites. Containerized stock should be used to reforest adverse sites in the Central Appalachian Piedmont regardless of whether they will be underplanted or planted in completely cutover sites.

Underplanting shortleaf pine beneath residual overstories may increase the likelihood of deer browse during winter months. Additionally, the stand conditions created by underplanting pine beneath a residual hardwood overstory may also predispose the stand to damage by redheaded pine sawfly. This is especially true on harsh sites, where underplanting may be most beneficial. Landowners should monitor underplanted sites and employ necessary control measures for deer and redheaded sawfly as necessary.
REFERENCES


