ABSTRACT

MEEKS, APRIL LAIL. Understory Competing Vegetation Characterization and Assessment in Midrotation Loblolly Pine (*Pinus taeda*) Stands at Hofmann Forest, NC. (Under the direction of Dr. Jose Stape, Dr. Douglas Frederick and Dr. Consuelo Arellano).

Regrowth of understory competing vegetation after thinning midrotation loblolly pine (*Pinus taeda*) plantations is frequent, diverse and can intensely compete for natural resources. Thinning opens the closed canopies allowing light to reach the forest floor. Additional light, in combination with disturbance, resets plantation succession. A growth spurt of shade intolerant herbaceous vegetation is typical in the open spaces, but decreases as loblolly pine leaf area increases. As shade takes over the forest floor, shade tolerant species, such as young hardwoods and evergreen shrubs, now have the opportunity to grow. Fertilization is often associated with midrotation thinning to promote the remaining loblolly pine trees to grow at maximum rates. Both loblolly pine and unwanted competing vegetation benefit from increased available nutrition.

To better understand the vegetation present during midrotation loblolly pine plantations, a visual assessment was conducted in 40 plots in the Lower Coastal Plain, NC at Hofmann Forest. The visual assessment was used to determine the level, or percent cover, and dominant species. The visual assessment was verified by quantifying the competing vegetation aboveground standing biomass by harvesting all living vegetation within a 3 m^2 transects. A subsample was dried, ground and analyzed for the relative nutrient content in the understory vegetation. Overstory loblolly pine leaf area index (LAI) was measured and foliage was analyzed for relative nutrient content. At the time of assessment, 17 plots were thinned and 23 unthinned.

From the visual assessment, 23 dominant species were identified as the main competing vegetation. Overall 6 plots were dominated by grasses, 11 were dominated by broadleafs and 22 dominated by woody vegetation. One plot had no vegetation. Forty-six percent of the plots contained high woody vegetation levels. Out of the 17 thinned stands, 12 plots had high vegetation levels; one had no vegetation, while 2 plots had medium and low vegetation levels. The 23 unthinned stands had 13, 7 and 2 control plots with high, medium and low vegetation levels, respectively. The most commonly identified dominant species were *Eupatorium*

capillifolium (dogfennel) and *Ilex coriacea* (large gallberry). Competing vegetation biomass ranged from 0 to 24 Mg ha^{-1} in thinned stands and 1 to 17 Mg ha^{-1} in unthinned stands. Pine LAI ranged from 0.6 to 2.0 m^2 m^{-2} and 0.7 to 1.9 m^2 m^{-2} in thinned treatment and control plots, respectively. Unthinned pine LAI ranged from 0.8 to 3.1 m^2 m^{-2} in the treatment and 0.8 to 3.3 m^2 m^{-2} in control plots. N content in competing vegetation ranged from 19.2 to 242.0 kg N ha^{-1} in thinned stands and 10.5 to 204.8 kg N ha^{-1} in unthinned stands. A single control plot, with high competition levels and grass vegetation on mineral soil, had 134.2 kg N ha^{-1} in the competing vegetation. High level woody competing vegetation averaged 109.8 and 111.2 kg N ha^{-1} in mineral (n = 11) and organic (n = 7) soils, respectively.

Overall, the visual assessment provides good estimates of competing vegetation biomass and nutrient content. The species identified were typical for Lower Coastal Plain environments in NC. A flush of herbaceous vegetation was observed in recently thinned, open canopy stands. Dogfennel was commonly found but is not a management concern because of its relatively low biomass and nutrient contents. Large gallberry was only found in undisturbed unthinned stands. The nutrient content for gallberry was around the average amount for all species. Plots with *Persea palustris* (swamp bay), *Lyonia lucida* (fetterbush lyonia) and volunteer loblolly pine had low loblolly pine LAI and highest nutrient content. The main factor affecting understory competing vegetation is the overstory loblolly pine LAI. Vegetation control temporarily suppresses growth of unwanted species.

Understory Competing Vegetation Characterization and Assessment in Midrotation Loblolly Pine (*Pinus taeda*) Stands at Hofmann Forest, NC

by
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DEDICATION

For my husband, Rick, for always believing in my ability to achieve anything and encouraging me to be the best scientist I can be. This work would not have been possible if it was not for the support you provided throughout this process. Thank you.

For my father and mother, where my roots began but my branches continue to grow.

BIOGRAPHY

April grew up in the foothills of North Carolina, in a wonderful home surrounded by nature. As a child, she was often found picking flowers, capturing insects, chasing wildlife and building forts in the forest. As she became older, her natural curiosity led her to explore many arenas such as art, math and psychology, but her passion has always been investigating the natural world.

April pursued a bachelor's degree in science at Appalachian State University in Boone, NC. She concentrated on environmental science, including advanced classes in environmental chemistry, physics, geology and biology. From the strong scientific and environmental background gained, she was particularly fond of forestry. Forests are important to all of Earth's cycles, acting as clean water and air filters, cycling nutrients through vegetative growth, assisting in forming rich soils, providing habitat for wildlife and so much more. The more she learned about forests, the more she needed to know, leading her to this project.

ACKNOWLEDGMENTS

I would like to thank Dr. Stape, Dr. Frederick and Dr. Arellano for all the assistance and guidance during this project, from literature to results. I would like to thank my fellow graduate students Kevin Hall and Yuan Fang for assisting with field work, protocols, writing and the daily activities of being a graduate student. I would like to thank all the undergraduate students who helped with field and lab work while keeping positive attitudes (in alphabetical order): Carolina Chaves; Michael Huculak; Marina Monto; Caroline Rodrigues; Nicole Stuardo. A special thanks to Dr. Jose Alvarez-Munoz and Tim Albaugh for the advice, guidance and feedback related to my work. To Itamar Bogona for the complete soil analysis with which this project could not have been completed without. To Dr. Glenn Catts for general Hofmann support and helping locate five hard to find plots.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Pinus taeda (loblolly pine) is a fast growing tree species naturally found across the southeastern United States (SEUS), on a range of soils and environments. It provides forest products, wildlife habitat, plant biodiversity and ecosystem services. Loblolly flourishes in native pine and mixed pine hardwood forests. There are currently 16 million hectares of pine plantations in SEUS planted for providing sawtimber, biomass, pulpwood, paper and other forest products (Schultz, 1997; Wear and Greis, 2013). Future forecasts of southern planted pine projects a potential range from 19 to 27 million hectares of plantations by 2060, depending on the future demand for wood products (Wear and Greis, 2013).

Due to enhancements in technology and research between forest industry, universities and US Forest Service (USFS) over the past 60 years, the SEUS has been named the "wood basket" of the world, increasing pine productivity in intensively managed plantations to possibly exceed 28 m^3 ha^{-1} yr^{-1} (Schultz, 1997; Fox et al. 2007b). The progress made from this collaborative research has allowed foresters to shorten rotations, increase productivity (Borders and Bailey, 2001) and successfully grow pine in areas where other species would out compete loblolly, such as *P. elliottii* (slash pine) and *P. serotina* (pond pine) in the Atlantic Coastal Plain. This progress in forest management is essential to support the current and future demands for loblolly pine in the SEUS, especially with the increased pressure from urbanization to produce more wood on less land. Additional pressure is added from increasing interest in producing biomass as an alternative fuel source. For example, Albaugh et al. (2012a) evaluated intercropping switchgrass, a potential biomass source, under loblolly pine plantations. Carbon storage in temperate forests, managed and unmanaged, is also gaining interest (Gough et al. 2008; Burton et al. 2013).

An observed positive response of pine productivity from intensive forest management prescriptions leads to questions about why and how the differences are happening (Neary et al. 1990; Schultz, 1997; Borders and Bailey, 2001). Improved tree growth is attainable from silviculture practices such as fertilization, irrigation, competing vegetation control, site preparation and genotype selection (Oppenheimer et al. 1998; Borders and Bailey, 2007; Fox et al. 2007a; Ferreira and Stape, 2009; Albaugh et al. 2012b). In a 25 year study, aimed at understanding the rotation length effects of intensive management practices in the SEUS, fertilization and competition control increased site index (base age 25 years) of loblolly pine from 20 to 27 meters, standing crop volume from 166 to 367 m^3 ha^{-1}, with a higher proportion (74 – 87 %) of high value product classes (chip and saw; sawtimber) in treated plots than in the control (39 %) plots (Jokela et al. 2010). Miller et al. (2003b) tested the effects of early competition control (first 3-5 years), without fertilization, on loblolly pine growth through 15 years; woody, herbaceous and woody plus herbaceous control increased merchantable pine volumes +14-118, +17-50 and 23-121 percent, respectively, compared to the no vegetation control. The biological response treatment order to silvicultural prescriptions was fertilization plus vegetation control > fertilization > vegetation control in 13 southern pine plantations (Albaugh et al. 2012b).

Trees require natural resources, including light, water and nutrients, to survive, grow and reproduce. Light, in the form of photosynthetically active radiation (PAR), provides the energy needed to drive photosynthesis. Light availability is optimized by planting in areas with long growing seasons with high sun exposure, but more importantly, increasing tree leaf area improves radiation interception. Increases in leaf area can be achieved by providing the necessary nutrient supply and growing space. Once radiation has reached the leaf surface, the species light use efficiency determines how much light (energy) is used to drive photosynthesis. Water is essential for the maintenance of cells, growing tissues, metabolic reactions and acts as a solvent to move gases and solutes in and throughout a plant (Pallardy, 2007). Water availability to a tree is determined primarily by the climate (precipitation; temperature; vapor pressure deficit; evapotranspiration) and the local geology (soil water holding capacity; water table depth). Nutrients are vital for plants to complete their life cycles. Different elements are necessary to create enzymes, act as catalysts, are constituents of plant tissues, along with many other functions (Pallardy, 2007). Nutrient availability depends on the soil characteristics, such as mineral versus organic and the parent material, but water is essential for nutrient availability. Water is often needed to transport available nutrients to the root surface area for absorption. Knowing what a tree needs to grow, and how the natural resources interact, provides the necessary information and insights for forest managers to increase pine productivity.

The Lower Coastal Plain region of North Carolina (NC) is important to forest mangers because loblolly pine develops optimally here compared to its counter parts in other regions. The climate is warm and humid with ample sun and accessible water. The Lower Coastal Plain is characterized as having low local relief, with large areas of poorly to very poorly drained soils (Daniels, 1999). Water is typically available throughout the growing season, because the water table is close to the rooting systems and precipitation occurs during the hot summer months. Even though trees need water to grow, too much water can hinder loblolly growth. During the growing season, trees grow best when the water table is kept at 60 centimeters below the surface or more (Schultz, 1997). Site preparation and silvicultural techniques, such as bedding and drainage, can improve survival and growth on poorly drained soils by raising the roots above the normal water table level, supplying the needed aeration to the root systems (Daniels, 1999; Fox et al. 2007b). Bedding improves drainage and improves nutrient availability. Soils in the Lower Coastal Plain are often limited in nutrition, mainly phosphorus (P) with low soil nutrient availability, limiting pine productivity (Neary et al. 1990; Fox et al. 2007a). Nutrition amendments such as liming and fertilization are often necessary to correct nutrient deficiencies and have shown to improve loblolly growth (Neary et al. 1990; Borders and Bailey, 2001; Martin and Jokela, 2004; Fox et al. 2007a; Jokela et al. 2010; Albaugh et al 2012b). When water is not a limiting factor, the differences in tree growth attributable to fertilization are the most distinct (Stape et al., 2004).

Another major constraint on forest growth is the competitive effects from the natural vegetation. Competition arises when the supply of natural resources, light, water and nutrients, is less than ideal. The Coastal Plain has diverse, dense and complex vegetative plant communities, ranging from grass-sedge marshes to evergreen shrubs to upland forests (Wells, 1928; Christensen et al. 1988). Competing understory vegetation interferes with forest productivity by using the natural resources otherwise available to crop trees (Neary et al. 1990; Allen and Albaugh, 2000; Martin and Jokela, 2004; Jokela et al. 2010). Understory here refers to the herb-shrub stratum and young hardwoods under pine canopies. Practicing forest vegetation management is necessary because competing vegetation affects crop tree survival and growth rates. However, little is known about species competitiveness or the treatment effects on levels and vegetative composition (Neary et al. 1990). By improving our understanding of how planted pine in the Lower Coastal Plain responds to silvicultural treatments in specific environments, foresters are better able to manage these plantations.

Competition for nutrients and water in the rooting zone occurs when competing vegetation is present. For example, woody shrub species such as *Ilex* spp. have dense root systems, responding quickly to available soil nutrients or fertilizers, outcompeting loblolly pine (Neary et al. 1990). The understory vegetative community is also dynamic, transitioning from herbaceous to woody plants, as the forest matures. Miller et al. (2003a) observed herbaceous plants initially increased with near complete woody vegetation control, in the first three to five years, while controlling herbaceous vegetation decreased shrub cover but increased hardwood cover, across 13 SEUS locations, grown for 15 years. By channeling resources to the targeted trees, loblolly pine, increases in site resource use efficiency can be made (Allen and Albaugh, 2000; Martin and Jokela, 2004; Jokela et al. 2010).

During midrotation, pine plantations are often thinned, reducing the stress of competition among loblolly pine trees, releasing the remaining target trees to grow. Commercial thinning removes salable trees, most likely die before harvest, so the remaining trees have additional space, and resources, to maintain near maximum potential rates of growth to reach the greatest value at the end of rotation (Schultz, 1997). After removing trees from the stand, there is an initial decrease in the canopy cover, allowing sunlight to reach the forest floor. The increased radiation at the forest floor level can cause a burst in competing vegetation growth because sunlight, once limited from the closed canopy, is now available to understory species. At this time, the main influences limiting pine growth are interspecific competition for resources, specifically nutrition. In 9 to 15 year old slash stands, located in the Lower Coastal Plain of FL and GA, annual midrotation competition control for ten years significantly increased height, basal area and merchantable volume growth (Oppenheimer et al. 1998).

Other midrotation silvicultural treatments include fertilization and competing vegetation control. Midrotation fertilization with nitrogen (N) (91 kg) and P (11 kg) can increase growth by an average 3.8 m^3 ha^{-1} yr^{-1} for an average of eight years because N and P often become limited around crown closure (Fox et al. 2007b). While fertilization can increase pine productivity, undesirable vegetation also benefits from the additional nutrition. An intense increase in competing vegetation productivity from fertilization can impede rather than facilitate loblolly pine growth. Albaugh et al. (2012b) tested the treatment differences between fertilization (N and P), vegetation control and fertilization plus vegetation control on midrotation pine (loblolly and slash) plantations, and commonly found fertilized stands yielded greater volume growth than the vegetation control only stands, but the combined treatment outperformed both individual treatments. This indicates available resources other than N and P were improved because the combined treatment effects were additive. Mechanical mowing and herbicides are intensive treatments employed within plantation forests should only be applied to satisfy profitability within environmental constraints and sustainability.

One method to measure the positive response from intensive management is using twin plots, with a treated and controlled plantation setting. The twin plot approach is a paired design with a normal operational management and a maximum silviculture plot aimed at estimating the difference between actual and potential productivity, and determining the main growth constraints (Stape et al. 2006; Ferreira and Stape, 2009). Actual productivity refers to the realized plantation growth, limited by poor nutrition, lack of water, competing vegetation, pests, disease and temperature. Potential productivity is maximizing growth by providing the natural resources required and reducing growth limiting factors. To estimate the differences between actual and potential productivity on a Lower Coastal Plain site in NC, the Forest Productivity Cooperative (FPC) installed 40 twin plots at Hofmann Forest. The twin plots span the entire 32,000 hectares providing a spatial evaluation of stands with the same climate, but with different silvicultural prescriptions. Using twin plots, in an operational setting at Hofmann Forest, assist in identifying the factors explaining the difference between actual and potential productivity.

Currently the natural competition, because of intensive silvicultural practices, on Hofmann midrotation loblolly pine plantations, is not well characterized, nor is the resource use from this vegetation well understood. Understory vegetation biomass and cover are often considered indicators of forest ecological processes. The data associated with these types of measurements have been used in modelling forest systems, and generally have weak predictive power, but can be improved with more complete understanding of the understory structure and stand disturbance history (Suchar and Crookston, 2010). As forest management improves, it is no longer feasible to assume vegetation control during midrotation has a positive cost-benefit ratio. To maximize pine productivity, at minimum treatment costs and environmental effects, requires site specific knowledge to model responses to different silvicultural intensities. Since competing vegetation can explain some of the variation in tree growth response, it is important to understand this interaction throughout the rotation and with disturbances. Experiments are needed to define critical periods of vegetation control, so the timing and duration of competing vegetation control can be optimized. The additional silvicultural treatments will affect the vegetative community under loblolly pine stands.

To determine the understory competing vegetation resource use in midrotation loblolly pine plantations, at a Lower Coastal Plain location, a research study including a visual assessment, a biomass harvest and a nutritional analysis was conducted over organic and inorganic soils at Hofmann Forest, NC. The visual assessment describes the percent cover and the competing vegetation type (growth form). Dominant species were determined during the visual assessment. This approach is quick, repeatable and simple. From the observed vegetation, the aboveground standing biomass was harvested, quantifying understory productivity. The harvested biomass was analyzed for nutrient content to provide the relative competing vegetation nutrient demands in relation to loblolly pine nutrient demands. The collected data provided site specific, baseline data for improved forest vegetation management at Hofmann Forest. The relationships and associations identified here can be used in other Lower Coastal Plain environments, specifically flatwoods.

HOFMANN FOREST

Hofmann Forest consists of approximately 32,000 hectares, spanning across Jones and Onslow counties in NC; latitude: 34.836° N; longitude: 77.303° W (Figure 1).

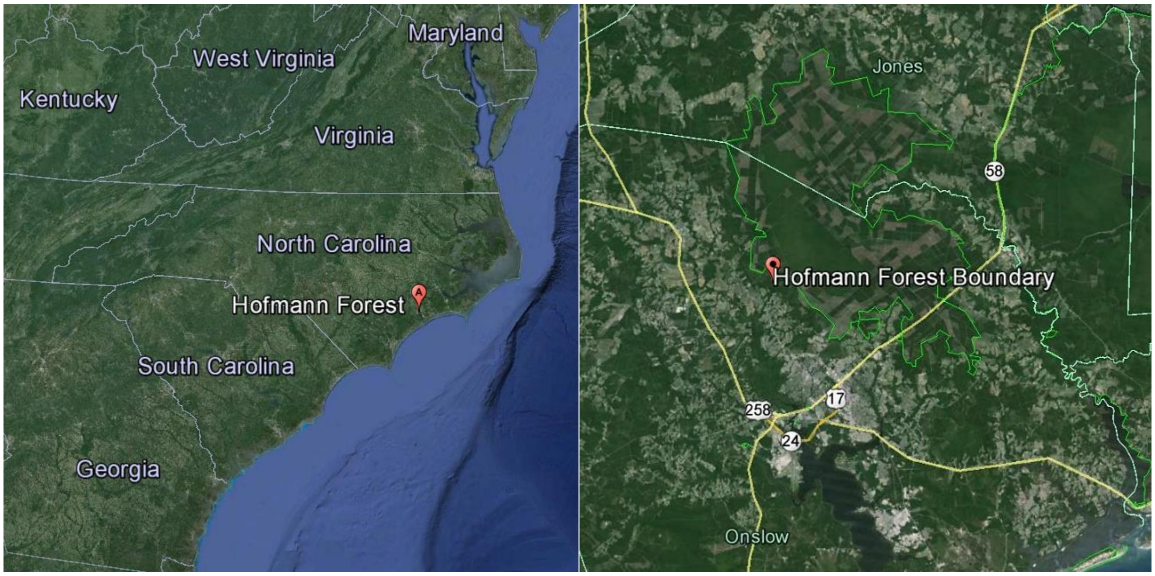


Figure 1: Location of Hofmann Forest in North Carolina (a) and the forest boundary (b), across Jones and Onslow County. (Source Google Earth)

Originally, the forest property was known as the White Oak Pocosin tract until it was purchased in 1934 by Dr. J.V. Hofmann, in association with the NC Forestry Foundation, Inc. (NCFF), for instructional use in the newly created Department of Forestry at North Carolina State University (NCSU) (Catts, 2010). Since 1936, the forest has been managed for timber production, constituting over 16,000 hectares of pine silviculture to support the College of Natural Resources educational efforts at NCSU. Historically, forest-product related activities and farming were performed on the land. Today, the forest is managed by NC State Natural Resource Foundation, Inc. and the military, public, university and hunting clubs, all have access to allocated forest sections. The forest is partitioned into different land use types to assist with strategic management planning. Table 1 shows the breakdown of land use types and the relative area of each.

Table 1: Forest management classes used for the strategic planning of Hofmann Forest (Catts, 2010).

Land Use Type	Total Area (ha)
Pine Silviculture	15,323
Reserved Area/Pocosin	7,137
Natural Pine Timber	4,802
Natural Pine not in Operations	876
Infrastructure/Roads	1,598
Hardwood Flats & Drains	1,378
Agriculture/Fire Break	711
Research & Conservation	305
Total	**32,130**

The climate at Hofmann Forest is variable but is generally consistent over the forest extent. The growing season usually lasts from April to October, but can last longer with rain throughout the year. The plant hardiness is classified as Zone 8a (-12 to -9 °C). Overall, average elevation is 14 meters above sea level. The normal annual minimum, mean and maximum temperatures are 10.6 °C, 17.2 °C and 23.8 °C, respectively. Normal annual precipitation is 143.3 centimeters. Monthly averages for the last 30 years (1971 to 2000) are found below (Figure 2).

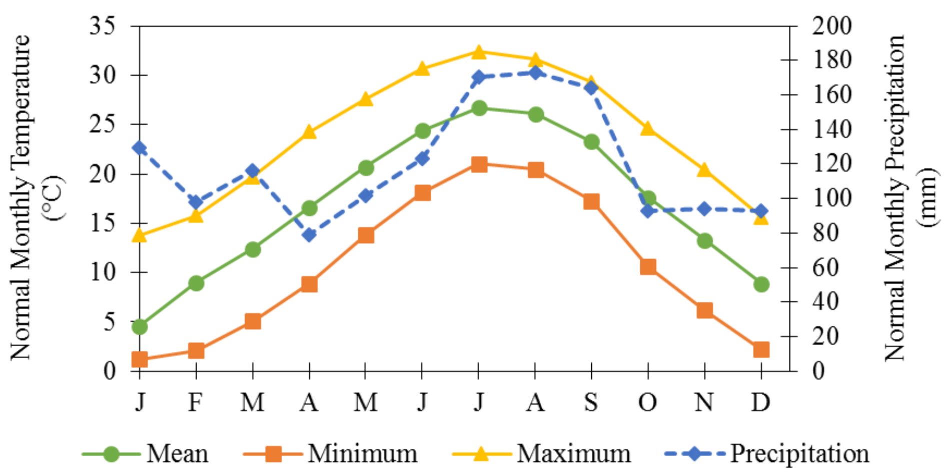


Figure 2: Monthly normal temperatures (solid lines) and precipitation (dashed line) for Hofmann Forest (Station 314144), Maysville, NC Onslow County from 1971 - 2000 (Data from CRONOS Database and NOAA).

Hofmann Forest is located on the Lower Coastal Plain Province, also referred to as the flatwoods Coastal Plain, in NC, Physiographic Province 2 (Atlantic Coastal Plain) and is dominated by planted pine (loblolly; slash). The forest has a large pocosin in the center. The Lower Coastal Plain is 29 meters below sea level with a low local relief of less than 1.5 meters elevation difference across three to four kilometers; soils consist of both organic and mineral and are poorly to very poorly drained (Daniels, 1999).

A soil profile analysis, up to 100 centimeter in depth, for each twin plot in the study was conducted by Forest Productivity Cooperative (Table 2) (FPC, 2013). Organic soils were Histosols, also known as peats and/or mucks because the organic material is well decomposed. Histosols are saturated with water for more than 30 days each year and contain at least 20 to 30 percent organic matter in more than half of the profile (Soil Survey Staff, 1999). The two main mineral soils were Spodosols and Ultisols. Spodosols have a unique B horizon with a high cation-exchange capacity and an accumulation of reddish or black materials, called the spodic horizon (Soil Survey Staff, 1999). Ultisols are usually formed from acidic parent materials. Ultisols have markers of intensive leaching, with higher base saturation in the upper few centimeters, decreasing with depth (Soil Survey Staff, 1999). One twin plot was classified as Inceptisol, a mineral soil, occurring in variety of climates and has a broad range of properties. An important characteristic of Inceptisols is the water availability to vegetation for more than half the year or greater than three consecutive months during the warm season (Soil Survey Staff, 1999). The soil taxonomy analyzed from Hofmann is listed in Table 2. A soil map and soil characteristics can be found in Appendix A-B.

Table 2: Soil taxonomy for the 40 twin plots within Hofmann Forest, NC (FPC, 2013).

Order	Great Group	Subgroup	Series	Number of Plots
Histosols	Haplosaprists	Typic Haplosaprists	Croatan (Ct)	11
			Pantego (Pn)	6
			Torhunta (To)	3
Inceptisols	Humaquepts	Typic Humaquepts	Torhunta (To)	1
Ultisols	Paleaquults	Typic Paleaquults	Rains (Ra)	7
			Pantego (Pn)	4
Spodosols	Alaquods	Histic Alaquods	Croatan (Ct)	2
			Pantego (Pn)	2
			Torhunta (To)	4

Loblolly pine is the dominant planted pine species at the Hofmann managed with the intention to grow the highest value product in the shortest amount of time. The intended operational rotation length varies from 21 to 33 years, based on site quality and management practices. In the plantation forestry zones, site index ranges from 21 to 24 meters at base age 25 years (SI_{25}) but can be increased to 27 meters SI_{25} when optimally managed (Catts, 2010). P deficient soils and inadequate surface drainage are the primary reasons for the differences in site performance.

Stand establishment practices include shearing, side casting slash, bedding and competing vegetation control using fire, mechanical equipment, herbicides or a combination of methods (Catts, 2010). Drainage ditches have been constructed to lower the water table during site preparation, but are not maintained after the plantation has been established. To protect soil and water resources, sedimentation is prevented from leaving the site using flashboard risers and the early drainage does not result in conversion to a non-wetland (Catts, 2010). Beds are constructed five to six meters apart to allow for thinning operations and typical planting is every five feet within the bed, targeted to maintain 988 trees per hectare with survival rates exceeding 90 percent (Catts, 2010). Major mortality risks include damage from hurricanes, pests and wildfires. Fertilization rates of 16 kilograms of P, commonly liquid diammonium phosphate (DAP), are required because the soils are generally P deficient (Catts, 2010). In addition to fertilization, herbicides are sprayed alongside the beds to control competing vegetation during early growth.

Stand maintenance is crucial to sustain the initial investments made during site preparation. Competing vegetation quickly overtakes the space between the planted beds and must be mowed at age three to four years. Selection thinning occurs around age 12, producing pulpwood, and then again at age 18 producing mostly sawtimber, chip and saw logs (Catts, 2010). Initial row thinning is required on sites with narrow bed widths. The target tree density is 494 trees per hectare after the first thinning and 247 trees per hectare after the second. Motivation behind thinning at Hofmann is to increase sawtimber production by directing site resources to the remaining crop trees. Additional management activities after thinning include controlled burns, to reduce competing vegetation, and fertilization on specific sites where needed; 225 kilograms N (175 kg Urea) and 27 kilograms P (27 kg DAP) per hectare may be applied (Catts, 2010).

The association of Hofmann Forest with NCSU allows forest research to be conducted by co-operation such as the FPC. The FPC works toward answering the concerns and interests of participating industry members. Research conducted by FPC includes field trials across the SEUS, with pine (loblolly and slash). FPC’s primary research goal is to determine the constraints on forest growth by evaluating and characterizing the differences between potential and actual productivity of loblolly pine in the southeastern US. Actual or observed productivity is the measured reality of how much a forest grew under site specific conditions. Potential productivity is how much a forest could grow under optimal conditions, no constraints, increasing the maximum amount a forest growth.

A research trial (Regionwide 22) was installed across Hofmann Forest (Figure 3) aimed at quantifying the difference between actual and potential productivity in the Lower Coastal Plain of NC.

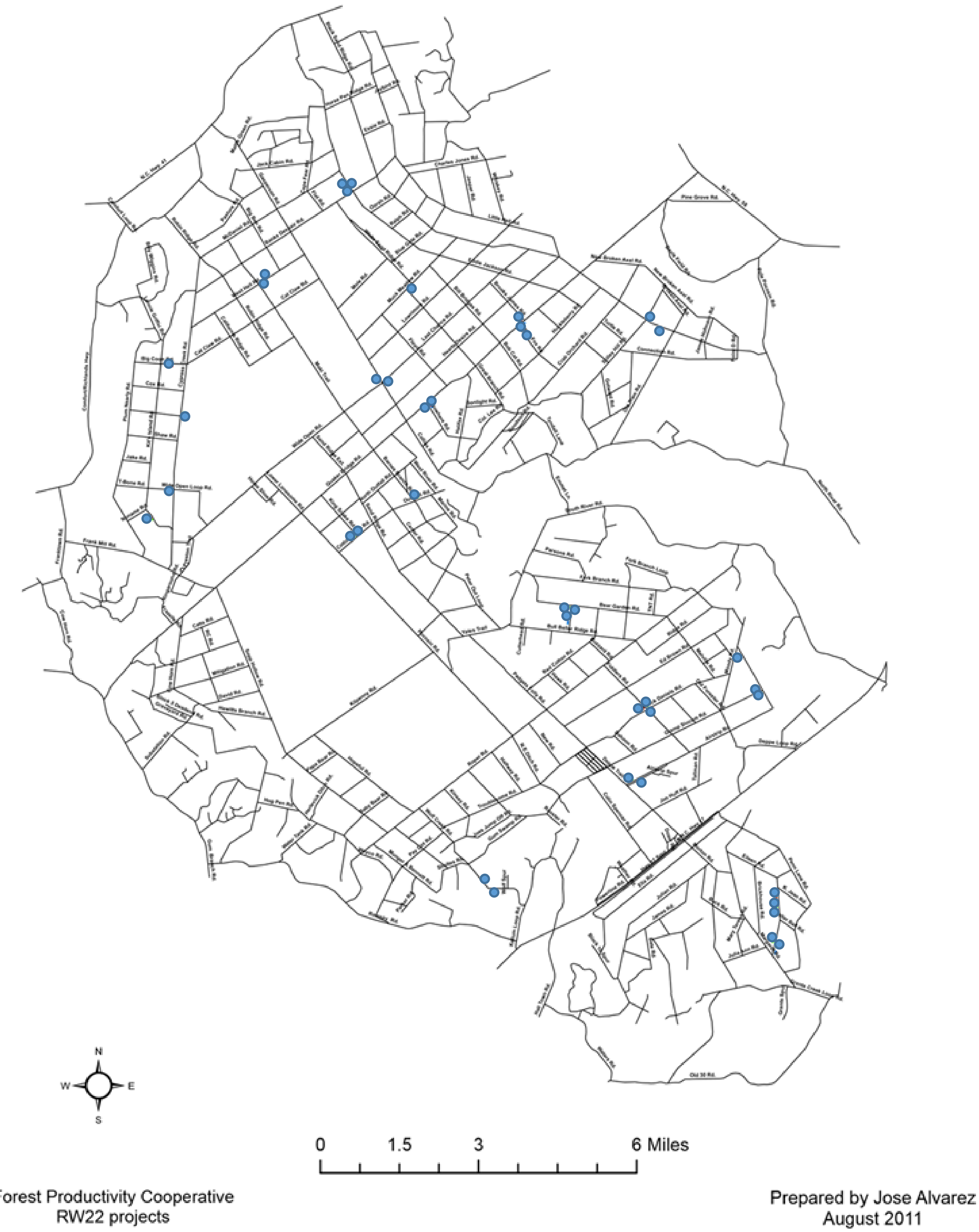


Figure 3: Twin plot locations (blue circles), installed by FPC in 2011, at Hofmann Forest, NC (FPC).

Permanent plots were previously established at Hofmann following the normal management procedures. A second plot was then installed in close proximity to the permanent plots, but received additional treatments (Figure 4). These paired plots are referred to as "twin plots" because they are identical in every aspect except they received varying silvicultural prescriptions. Each twin plot is one block with a control and treatment plot. The control (permanent) plot receives the standard operational silvicultural prescriptions issued by Hofmann Forest management. The treatment plot receives the standard operational silvicultural prescriptions combined with complete and sustained weed control and intensive fertilization intended to eliminate any nutrient limitations. Advantages of using a twin plot approach are the environmental variables, radiation, temperature, vapor pressure deficit and precipitation, are consistent for both plots. Other equivalent variables include the initial stand characteristics, productivity, site preparation, geology and soil characteristics.

Forty twin plots were established in 2011 on Hofmann Forest (Figure 3). To ensure the treated and control plots were identical, a t-pair test (within 10%) was conducted using the initial stand measurement to show the plots were less than ten percent different from each other, or not statistically different. The dimensions of each measurement plot were identical (0.10 ha) and chosen with the intention of having 25 live trees at the end of the study (Figure 4). The stands selected ranged from four to eight year old. Thinning was allowed and conducted by Hofmann operational procedures as long as 25 live trees remained. Age and thinning details for each twin plot is included in the Appendix C. Competing vegetation control in the treated plots included site specific methods developed in consultation with Hofmann management to ensure complete vegetation control. The first year fertilization included macro and micro-nutrients to all sites (Appendix D). Additional fertilization, with 112 kilograms elemental N per hectare, occurred before the third year of growing. Mechanical and chemical (Appendix E) treatments were used based on the conditions and needs of each stand. FPC conducted yearly foliage analysis to test for nutrient limitations and any elements detected to be limiting growth, had additional applications on a site specific basis.

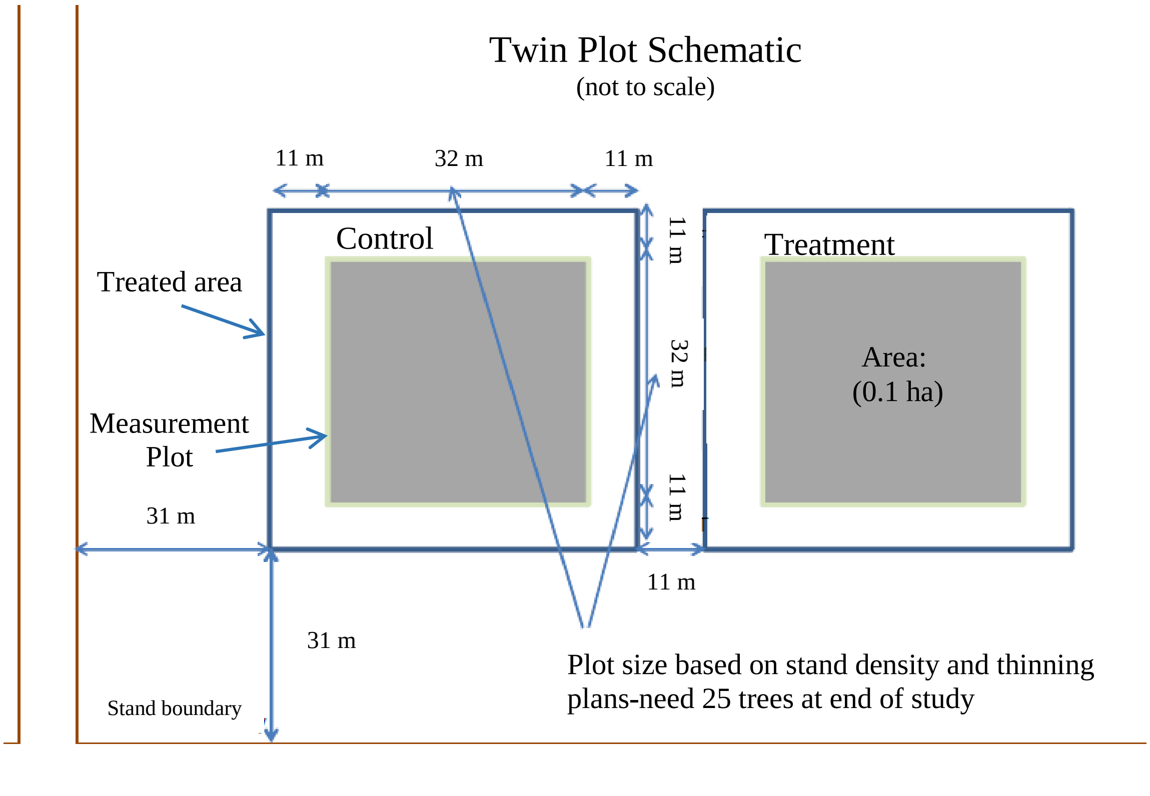


Figure 4: The dimensions of the twin plots and placement next to each other at Hofmann Forest. All twin plots were established in 2011 and were based on these dimensions. Control plots received normal Hofmann management. Treatment plots received additional fertilization and complete competing vegetation control.

VISUAL ASSESSMENT

1. Characterization of understory competing vegetation (UCV) across a loblolly pine plantation landscape in the Lower Coastal Plain of North Carolina

1.1 Introduction

Loblolly pine is in competition with other plants, annuals and perennials, throughout its life cycle. The natural succession of loblolly pine begins after a disturbance (fire; hurricane; harvest; clear-cutting), followed by a burst of annual herbaceous vegetation, then development of pine or mixed pine-hardwood stands, ending with a hardwood climax community (Schultz, 1997). Natural loblolly pine is considered a strong competitor on disturbed sites, out competing other pines and hardwoods initially, making it a pioneer species. Herbaceous vegetation, including grasses, grass-like species, forbs and ferns, also respond quickly to the recently disturbed soil, because seeds are now exposed to the surface, receiving the resources necessary for germination. This spurt of herbaceous growth continues until the young pines reach canopy closure and shade out the herbaceous vegetation. During this burst of growth, pioneer herbaceous vegetation interferes with pine growth by using the available natural resources, light, water and nutrition, otherwise available to loblolly pine (Cox and Van Lear, 1984; Stansky et al. 1986; Schultz, 1997). As the forest matures, slower growing hardwood species and woody shrubs become more prominent. Shade tolerant woody species can benefit from the closed canopy. Eventually, hardwoods will overtake the canopy and become dominant, suppressing loblolly.

In a plantation, competing vegetation mimics the natural succession, but can also be more intense because silvicultural practices, like fertilization, can increase stress due to the additional nutrition boosting vegetative growth of undesired species. In wet environments, where water is not limiting, competition can also be more intense. During the first four years of growth on a Coastal Plain site in Florida, controlling competing vegetation had a similar response as annual fertilization did on pine growth (Neary et al. 1990). Removing the unwanted vegetation reduced the competition for mineral nutrients in the soil, allowing the young pine to retain the necessary nutrition, improving growth and survivability. Zutter and Miller (1998) report an increase in loblolly pine growth response after 11 years of herbaceous and woody vegetation control on a Lower Coastal Plain flatwoods site in Georgia; controlling both vegetation types had a greater response than controlling woody or herbaceous alone. The first few years after planting, herbaceous vegetation control is necessary to release the seedlings to grow. As the stand matures, woody species develop, therefore, their control is imperative and they will outcompete pine for resources and space.

Controlling hardwood competition improves the survival and growth of pine. Clason (1993) reported suppressing hardwoods in addition to controlled stocking, burning and thinning, on a planted loblolly pine plantation in Louisiana, increased biological and economic productivity through a 27 year rotation. Another current concern in vegetation management is the case of volunteer pines present on pine plantations. The herbicides used to control hardwoods are developed to target the undesired species without harming loblolly pine, but there are no herbicides to control volunteer pines without harming the crop tree (Fox et al. 2007b). Controlling herbaceous vegetation, from establishment to canopy closure (age 12), on a range of site qualities (low; medium; high) in the SEUS, improved standing total volume and shortened the time to thinning (Glover et al. 1989). The volume increases from managing herbaceous species growth allows loblolly pine to have access to limited site resources otherwise available to the unwanted vegetation. Another study tested herbaceous control at 16 locations across the SEUS and found a statistically significant positive response of two to seven year old planted pine diameter and height growth in all the trials (Creighton et al. 1987).

One unique ecosystem in the Lower Coastal Plain region of North Carolina is forested wetlands called pocosins or “swamp-on-a-hill” (Tooker, 1899). These areas are also called bays, baylands, bay head, bay forests, evergreen shrub bog, swamp forests, wet upland bogs, xeric shrub bog (Wells, 1928; Miller and Maki, 1957; Christensen et al. 1988; Richardson, 2003). Pocosins have poor natural drainage due the low gradient, typical of Lower Coastal Plain environments, with sands, silt or clay overlain with varying depths of black muck (Miller and Maki, 1957; Daniels, 1999). Interestingly, 70 percent of the United States’ pocosins are in NC where they comprise more than 50 percent freshwater wetlands (Richardson et al. 1981;

2003). The Hofmann Forest has a large pocosin in the center and influences the vegetative community throughout the forest and its surroundings.

The native vegetation in a pocosin is evergreen shrubs, cane beds, with low densities of pines in dryer areas (Wells, 1928; Miller and Maki, 1957). The distribution of vegetation is influenced by areas of regular flooding and standing water. The high water table, flat land and mucky, poorly drained soils, keeps water at the surface for long periods throughout the year. Here, the plant community is known as the Pocosin, bayland, shrub bog or broadleaved, evergreen shrub community (Wells, 1928). The Pocosin plant community is dominated by *Ilex glabra*, *Morella carolinensis*, *M. cerifera*, *Cyrilla racemiflora*, *Arundinaria macrosperma*, *A. tecta*, *Magnolia virginiana*, *Osmunda cinnamonea*, *Acer carolinianum* (small), *Pieris mariana*, *P. nitida*, *Liquidambar styraciflua*, *Smilax laurifolia*, *Sphagnum* spp., and *Tamala pubescens* (Wells, 1928). Some of the subdominants include *Andropogon* spp., *Gordonia lasianthus*, *Ilex myrtifolia*, *Pinus taeda* and *Smilax glauca* (Wells, 1928).

The Pocosin vegetative structure is important in a plantation environment such as Hofmann Forest where drainage occurs. As the habitat becomes wetter, *Cyrilla racemiflora* becomes more prominent, but with the reverse process, and drainage is introduced, *Ilex* and *Morella* become dominant (Wells, 1928). The slight changes in topography also affect the natural vegetation, even with an overall low relief across the area. Elevated areas are considered short pocosins, or ombrotrophic shrub bogs, occurring over nutrient deficient, deep peat accumulations greater than one meter (Richardson, 2003). The deepest organic deposits at Hofmann are found in the open pocosin where an impenetrable shrub understory has formed from 50 years without burning (Catts, 2010). Tall pocosins typically have a greater vegetation height and aboveground biomass than short pocosins. Tall pocosins are found over shallower peat accumulations, with great soil nutrient content (Richardson, 2003). Bay forests occur along out-flow stream drainages, relatively nutrient rich, and have a range of organic matter (Richardson, 2003). In other pocosin areas, periodic burning determines the understory height and vegetation type; areas with frequent fires have low pocosin vegetation, while areas with low fire frequency have high cover (trees) and cane shrubs dominate over typical evergreen shrubs in the presence of fire (Wells, 1928). The dominant species found in all of these environments are comparable, but have varying abundances, basal areas and heights. For instance, in a tall pocosin, the numbers of shrub and tree stems per hectare are decreased compared to short pocosin and herbaceous vegetation is highest in short pocosins, followed by tall pocosin and lowest in bay forests (Richardson, 2003).

The species common to the pocosin environment have also been observed in other coastal environments. Broomsedge, bluestem (*Andropogon* spp.) and panicgrass (*Dichanthelium* spp.; *Panicum* spp.) species have been noted as dominant species in Lower Coastal Plain environments (Neary et al. 1990; Zutter and Miller, 1998; Miller et al. 2003a; Martin and Jokela, 2004). Pioneer grasses, such as broomsedge, often compete with pine seedlings for natural resources and their populations can be denser and more competitive on productive sites (Schultz, 1997). Woody evergreen shrubs, such as *Ilex* species, *Lyonia* species and *Cyrilla racemiflora*, have been surveyed in other Lower Coastal Plain environments (Oppenheimer et al. 1989; Zutter and Miller, 1998; Miller et al. 2003a; Martin and Jokela, 2004). These species have also been observed as far west as Texas. Observations of herbaceous and woody plant community under pine-hardwood forests, in eastern Texas, identified *Panicum* spp., *Carex* spp., *Solidago* spp., *Gelsemium sempervirens*, *Rhus toxicodendron*, *Vitis rotundifolia*, *Smilax* spp., *Ilex opaca*, *Rubus* spp. and *Myrica cerifera*, to name a few (Stransky et al. 1986).

Since the vegetative community of southeastern coastal pine plantations is diverse, generally complex and changes with the stand age, studies regarding its presence throughout the rotation are limited. On landscapes where soil moisture is not the main limiting resource, shrub and hardwood competition begins early in the rotation and continues to intensify with age (Oppenheimer et al. 1989; Schultz, 1997). There is indication the vegetation type and the relative quantity matters, because most vegetation interferes with loblolly pine productivity. Early studies from establishment through canopy closure, regarding the effects of herbaceous and woody vegetation on pine growth, have been documented (Creighton et al. 1987; Glover et al. 1989; Zutter and Miller, 1998; Borders and Bailey, 2001). Other research has investigated the rotation length effects of competition control and fertilization on pine productivity (Clason, 1993; Jokela et al. 2010). The specific effects of midrotation competing vegetation are poorly understood, but are necessary to identify what types and species are affecting resource availability, if any. This is of even greater importance when fertilization, a common midrotation silvicultural practice, is also conducted. Zutter and Miller (1998) commented on the resiliency of competing vegetation, indicating early herbaceous and woody control was only suppressed with herbicide use and once cessation of those treatments, re-establishment occurred and their presence would continue to influence pine growth through midrotation.

1.2 Objectives

1. Determine midrotation loblolly pine plantation understory competing vegetation conditions using a visual assessment for the 40 twin plots at Hofmann Forest, NC.
    a. Determine the level and type of midrotation competing vegetation.
    b. Identify the dominant and co-dominant species in the control plots.

1.3 Methods and Materials

The visual assessment code (Table 3) was developed by the Forest Productivity Cooperative (FPC), to categorize observations of competing vegetation by how much and what vegetation types were present on loblolly pine plantations (FPC, 2010). Prior to using the assessment, each person was trained to classify environments using the visual code. Training consisted of directing how each plot should be viewed and categorizing what was seen. Once an area was inspected, all trainees would discuss the field results to compare and contrast observations. Any conflicting observations were discussed. Training was conducted in varying environments to ensure consistency by each person. The inherent difference between evaluators was minimized, to some degree, with training and experience.

Visual assessment was conducted in the 40 twin plots at Hofmann Forest, NC during the 2013 growing season, starting in May and ending in September 2013. The assessment was conducted in the treatment and control plots. Previous assessments (2010, 2011, 2012) were conducted by trained FPC interns and those observations are included in this study. A minimum of three trained observers investigated the UCV situations, independently. Observers selected the visual code without discussion among themselves. Visual assessment consisted of assigning a three letter visual code to each plot (Table 3). Understory refers to the herb-shrub stratum and young hardwoods present under mature pine canopies.

Table 3: Visual assessment code developed by the Forest Productivity Cooperative (2010).

Grades	Codes	Description
1) **Level** of Competing Vegetation	**H**	High (> 2/3 = 67%)
	M	Medium (1/3 to 2/3 = 33% to 67%)
	L	Low (1/20 to 1/3 = 5% to 33%)
	N	None (< 1/20 = 5%)
2) **Dominant** Competing Vegetation Type	**B**	Broadleaf
	G	Grass
	W	Woody
	A	Absent
3) **Co-Dominant** Competing Vegetation Type	**B**	Broadleaf
	G	Grass
	W	Woody
	A	Absent

NOTE. - Three letter code for the visual assessment describes 1) level of living understory competing vegetation found, expressed as the percent of ground covered by vegetation; 2) type of the dominant understory competing vegetation species; 3) type of co-dominant understory competing vegetation species (FPC, 2010). Grass includes rushes and sedges; broadleaf includes forbs and vines, both herbaceous and semi-woody; woody includes trees, arborescent species and woody shrubs; none refers to situations when there was less than five percent living vegetation present.

First, the level of living competing vegetation occupying the ground was chosen, expressed as the percent cover by UCV. Percent cover is defined as the percent of soil surface covered by the aboveground plant (vertical projection) and is typically expressed as a percentage (Miller and Glover, 1991). Each observer walked the plot boundary to view the ground area from all sides and the vegetation from all aspects. Next, the observer walked in transects across the rows of planted pine, parallel with rows and diagonally through the plot. The UCV height was considered and overall ground area covered by vegetation, compared to patches of visible ground. Only living, green vegetation was considered. Dead standing vegetation was not. Then a level, high, medium, low or none, was assigned.

High level was a plot with 67 percent or more UCV covering the ground (Figure 5). Generally, little to no bare ground was visible when viewed from eye level. The vegetation height would vary, ranging from one to three meters or higher. These plots were the most difficult to walk through, with many obstacles requiring the help of clippers and tools to walk through. Visibility across the plot was low, little to none. Observers could see the next row of planted pine, but not always.

Medium level was a plot with 33- 67 percent of the ground occupied by UCV (Figure 5). Areas of bare ground were observed. Medium level plots percent cover varied, having areas with no vegetation with patches of dense, taller vegetation. Vegetation height ranged from ground level vegetation to small trees, single volunteer hardwood species. Observers walked through these plots with less obstacles, compared to the high level. Visibility within the stand was across one or more rows of planted pine.

Low level plots had 5-33 percent of ground occupied by living competing vegetation (Figure 5). Low plots were predominately bare ground, or a leaf litter layer, with smaller and fewer patches of vegetation than the medium level. Vegetation height was generally one meter or less. Observers walked through the plots with few obstacles. Visibility was clear across several rows. None level plots had five percent or less ground covered by vegetation (Figure 5). The ground was generally bare, exposed or a leaf litter layer, but with few, if any, single living, growing plants. Plant height was generally one meter or less. None plots were the easiest to walk through with no obstacles. Visibility was clear across the entire plot.

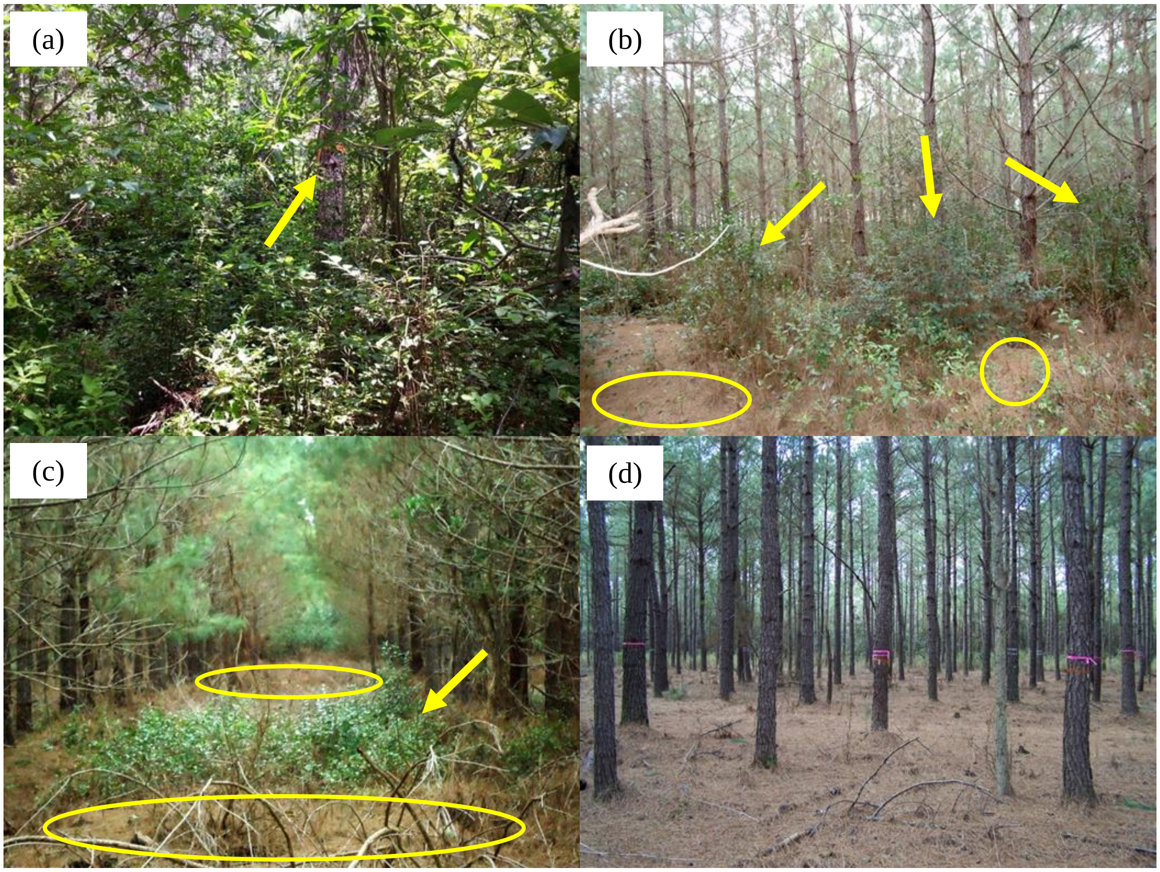


Figure 5: Photo examples of high (a), medium (b), low (c) and none (d) understory competing vegetation levels observed at Hofmann Forest, NC during 2013 growing season. The visibility in a high (a) level plot is low; notice how difficult it is to see the flagging (arrow) on the crop tree. Medium (b) level plots have areas of bare ground (circles) with patches of denser, taller vegetation (arrows). Low (c) level plots are predominantly bare ground or leaf litter (circles) with a patch of vegetation (arrow) covering between 5-33 percent of ground. None (d) level plots have less than five percent competing vegetation present on the ground and visibility is clear across the plot.

Second, the dominant UCV type was determined. A dominant species was defined as a species having many individuals, dispersed throughout the observed area, and will be numerous compared to the other vegetation. Dominant species are recognized by being the tallest vegetation, occupying most of the understory canopy, composing the bulk of the biomass in the understory. Dominance estimates the amount of control a certain group of plants or species has over the site's resources (Miller and Glover, 1991). The understory dominant competing vegetation type was expressed as one of the following: grass, broadleaf, woody or absent (Figure 6). The species type category is based on plant growth forms.

Here, broadleaf refers to flowering plants (angiosperms) with wide, broad leaves instead of needles and narrow, grass-like leaves. The broadleaf category includes herbs, forbs, subshrubs and vines. Herbs are a plants with little to none above-ground perennial woody tissue (Murrell, 2010). Forbs include herbaceous vegetation, non-graminoid, such as ferns. Subshrubs are not entirely woody, but have the structure of a shrub with some lower stiff perennial woody tissue with herbaceous tops (Murrell, 2010). Vines include herbaceous, woody and semi-woody vines. Examples of vine species included are *Vitis* (grape), *Gelsemium sempervirens* (evening trumpetflower) and *Smilax* (greenbrier) species.

The grass category included species within the following families; Poaceae (true grasses), Juncaceae (rushes), Cyperaceae (sedges). True grasses are those species under the family Poaceae (Gramineae) (Murrell, 2010). Grasses are recognized by their fibrous root systems, two linear open basally sheathing leaves and generally have long, narrow leaves (Murrell, 2010). Sedges and rushes are in the same order (Poales) as the true grasses but have varying features such as closed basal sheaths (Murrell, 2010). All three are often referred to as graminoids (USDA NRCS, *available online*).

Woody category refers to trees and arborescent (tree-like) species. Woody shrubs and semi-woody shrubs, like *Rubus* (blackberry), are also included. Volunteer loblolly pines are included in the woody competing vegetation type. Shrubs are woody perennial plants with one to many relatively thin trunks/stems coming from near the base (Murrell, 2010).

Absent refers to situation when no vegetation is present. Less than five percent of the ground area has living vegetation. The ground will mostly be dead vegetation and pine litter.

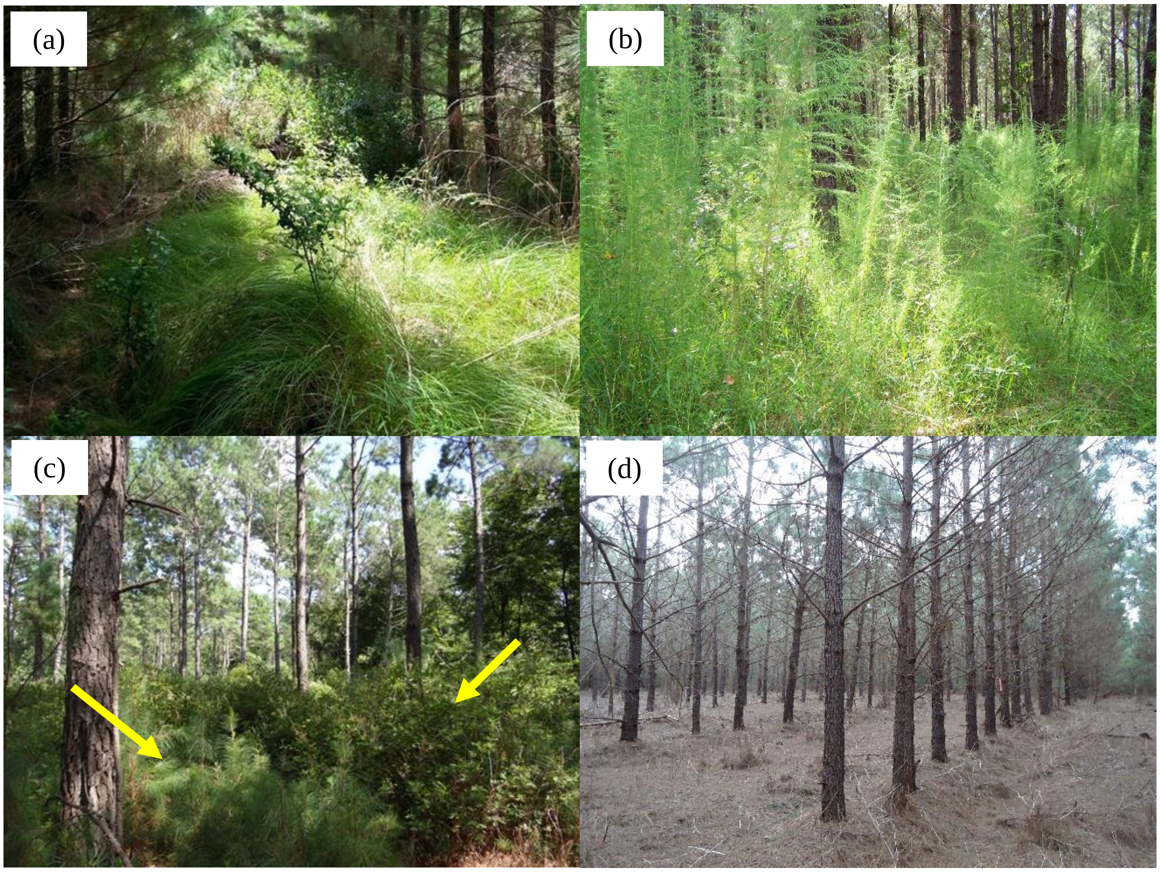


Figure 6: Photo examples of plots where grass (a), broadleaf (b), woody (c) and absent (d) types were the dominant understory competing vegetation observed at Hofmann Forest, NC during 2013 growing season. Grasses (a), is *Carex glaucescens* (southern waxy sedge), are shown covering the ground area between the rows of planted pine; other vegetation types are present but grass species make up the bulk of the biomass and cover most of the ground area. Broadleaf species *Eupatorium capillifolium* (dogfennel) shown (b) as a dominant broadleaf type because it is the tallest species, making up most of the canopy. Two woody species dominant this plot (c), shown by arrows, because of their abundance and height; species are *Pinus taeda* (loblolly pine) and *Ilex coriacea* (large gallberry). Absent (d) shows an environment where there is little living vegetation.

Third letter for the visual assessment code represented the co-dominant UCV type. The co-dominant vegetation type followed the same method as the dominant, second to the dominant species. The co-dominant vegetation type is the second most numerous species, comprising a portion of the canopy and understory biomass, but only second to the dominant species. If a plot had only one species, dispersed throughout the plot, absent would be the co-dominant vegetation type. For example, a plot with a uniform understory cover of volunteer loblolly pine with no other vegetation present would be classified as woody-absent. If a plot were classified as having none for the UCV level, it would have absent listed for the dominant and co-dominant species because there cannot be a species type without vegetation cover.

Identification of UCV species was conducted in the field, after the visual assessment. Using field guides (Kirkman, 2007; Miller and Miller, 2005) the dominant species were recorded at each control plot. In situations where the observers were unfamiliar with a species and/or having difficultly identifying using the field guides, a sample was clipped and brought to the lab for further classification (Radford et al. 1968). Observers would collect a living plant sample by cutting and gathering leaves, reproductive material, bark and roots, where applicable. Cuttings were placed in gallon Ziploc bags, labeled and placed in a cooler until returned to the lab. Species photographs in the field were taken. Plants were pressed and dried in an oven for 48 hours at 65°C, then mounted and labeled. The Manual of the Vascular Flora of the Carolinas and Vascular Plant Taxonomy were primarily used for identification (Radford et al., 1968; Murrell, 2010).

A visual assessment was conducted at Hofmann Forest twin plots during the 2013 growing season. Previous visual assessments were performed in the twin plots prior to this study, starting in 2010. Overall, four years covering three growing seasons were assessed. The first assessment was at the end of the growing season, starting in September and ending in November 2010. The next assessment was in March 2011, at the start of the growing season, followed by a summer assessment in June 2012. In 2013, visual assessments were conducted in May, July and September, the growing season end. Every assessment was conducted by a different team of trained observers. The visual code assigned by the individuals during each observation period was consistent. Both the treatment and control plots were observed in each twin plot. Visual assessment in the treatment plots assisted in determining when vegetation control was needed. Any plot classified as medium (M) would receive additional vegetation control to maintain the percent cover at or below low (L) levels.

1.4 Results

1.4.1 Visual Assessment Code

The visual assessment results from 2010 to 2013 for the treatment and control plots can be found in Table 4 and 5. Results are organized by thinned versus unthinned stands, and then by forest age to show the youngest to oldest stands. By 2013, 17 twin plots at Hofmann had been thinned by harvesting every fourth row, with additional thinning of selected trees. Only one thinning occurred in each stand. Late 2013 growing season (September) results were used for analysis in this report because other measurements were taken at this time; Table 4 and 5 have a yellow box around the September 2013 results used hereinafter.

Table 4: Visual assessment results for treatment plots, 09-2010 to 09-2013, at Hofmann Forest. Bolded cells are twin plots where vegetation is above desired level and requires additional control. Cells with missing information were due to management activities, preventing safe observation. Thinned twin plots are presented first. Stand age in 2013 is provided. September 2013 results used hereinafter.

			Visual Assessment					
Twin Plot	Thinning Date	Age (2013)	2010 (Sept-Nov)	2011 (March)	2012 (June)	2013 (May)	2013 (July)	2013 (Sept.)
21	2013	10	NAA*	NAA	LBA	NAA	NAA	NAA
29	2012	10	NAA	NAA	NAA	LBA	LBA	LBA
25	2012	12	NAA	NAA	---	NAA	LBG	LBG
17	2013	14	LBW	NAA	LWA	NAA	LGB	LBG
23	2012	14	NAA	NAA	NAA	---	**MBA**	LBA
11	2010	15	NAA	NAA	NAA	NAA	NAA	NAA
3	2006	18	NAA	NAA	LBA	NAA	NAA	NAA
18	2006	19	NAA	NAA	LWA	NAA	NAA	NAA
34	2008	19	NAA	NAA	LBG	NAA	NAA	NAA
1	2005	21	NAA	NAA	LGB	NAA	**MBA**	LBA
8	2003	21	NAA	NAA	LWA	NAA	LBA	LBA
9	2003	21	NAA	NAA	LWA	NAA	LBA	LBA
13	2004	21	LBA	NAA	LWB	NAA	LWA	LWA
36	2007	23	LGB	NAA	LWB	NAA	LBA	LBA
37	2007	23	LWA	NAA	LWA	**MBW**	**MBG**	LBG
40	2008	23	NAA	NAA	NAA	LGB	NAA	NAA
31	2004	24	NAA	NAA	NAA	NAA	LBA	NAA
2		4	NAA	NAA	NAA	LBA	LWB	LWB
22		4	LWG	LWA	LBG	LBB	**MBB**	LBB
33		4	LGB	LBG	LGB	**MBW**	**MWG**	LWG
35		4	NAA	NAA	LGW	**MWA**	**MWB**	LWB
4		5	LWA	NAA	LBW	LBB	LBA	LBA
15		5	LBW	NAA	LGB	NAA	**MWG**	LWG
30		5	LWB	LBW	LGW	LBB	LWA	LWA
16		6	NAA	NAA	LBG	LBB	LGA	LGA
26		6	NAA	NAA	LBA	NAA	LBA	LBA
38		6	NAA	NAA	NAA	NAA	NAA	NAA
10		7	NAA	NAA	NAA	NAA	LBA	LBA
12		7	NAA	NAA	NAA	**MBB**	NAA	NAA
24		7	LBA	LBA	LBW	NAA	LBG	NAA
28		7	NAA	NAA	NAA	NAA	LGA	LGA
14		9	NAA	NAA	NAA	NAA	**MBA**	LBA
20		9	NAA	**MWA**	**MWA**	NAA	**MBA**	LBA
5		10	NAA	NAA	NAA	NAA	NAA	LBA
27		12	NAA	NAA	LBA	NAA	**MBG**	LBG
39		12	NAA	NAA	NAA	LBB	**MGA**	LGA
32		13	NAA	NAA	LWA	NAA	LBG	LBG
19		14	NAA	NAA	NAA	NAA	**MBA**	LBA
6		16	NAA	NAA	NAA	NAA	LBA	LBA
7		16	NAA	NAA	NAA	NAA	LBA	LBA

* H = high; M = medium; L = low; N = none; B = broadleaf; G = grass; W = woody, A = absent.

Table 5: Control plot visual assessment results, 09-2010 to 09-2013, at Hofmann Forest, NC. Bolded cells indicate visual assessments conducted after thinning. Cells with missing information were due to management activities (harvesting) within the twin plot, preventing safe observation. Thinned twin plots are presented first. Stand age in 2013 is given. September 2013 results used hereinafter.

			Visual Assessment					
Twin Plot	**Thinning Date**	**Age (2013)**	**2010 (Sept-Nov)**	**2011 (March)**	**2012 (June)**	**2013 (May)**	**2013 (July)**	**2013 (Sept.)**
21	2013	10	MWB*	HWB	HBW	HWB	HWB	**LBW**
29	2012	10	MWB	MWB	HWB	**HWB**	**HWB**	**HBG**
25	2012	12	LWA	MWW	---	**LBB**	**LBB**	**HBG**
17	2013	14	HGB	MWB	MWB	**LWB**	**LWB**	**LGB**
23	2012	14	MBA	MWB	MBW	---	**MBG**	**MBG**
11	2010	15	**MBA**	**MWB**	**MWB**	**MBW**	**MBW**	**MWW**
3	2006	18	**MBW**	**MBW**	**MBG**	**LBG**	**MWG**	**NAA**
18	2006	19	**MWA**	**MWB**	**MWB**	**HBB**	**HBB**	**HWB**
34	2008	19	**HWB**	**HWB**	**HWB**	**HWB**	**HWB**	**HWB**
1	2005	21	**MBG***	**HWB**	**MWG**	**HWB**	**HWB**	**HWW**
8	2003	21	**MWG**	**MWB**	**MWB**	**HWB**	**HWB**	**HWB**
9	2003	21	**MWB**	**MGW**	**MWB**	**HWB**	**HWB**	**HWG**
13	2004	21	**HBG**	**HWB**	**MWB**	**HBB**	**HBB**	**HWW**
36	2007	23	**MGB**	**HWB**	**MWB**	**MWB**	**HWB**	**HWW**
37	2007	23	**MWB**	**MBW**	**LWA**	**HWB**	**HWB**	**HBG**
40	2008	23	**HBW**	**HWB**	**HWB**	**HWB**	**HWB**	**HGW**
31	2004	24	**HBW**	**HBG**	**HBW**	**HWB**	**HWB**	**HWW**
2		4	HBW	LBB	MBG	HBB	HBB	HWW
22		4	MGW	MGB	MGB	HBB	HBB	HWB
33		4	MWG	NGA	MBG	HWB	HWB	HWB
35		4	MGW	MWB	MWB	HBB	HBB	HBB
4		5	HWB	HBG	MBG	MBB	LBB	MBW
15		5	MGB	MGB	MGB	MGB	MGB	MGB
30		5	HWB	HWB	HWB	HBB	HBB	HWW
16		6	MGB	MBG	MBW	HWB	HWB	HWW
26		6	MBW	HBB	MBW	HWB	HWB	LWB
38		6	HBW	HBW	HBW	HBB	HBB	MWB
10		7	MWB	HBB	MBA	HWB	HWB	HWW
12		7	MBG	HBG	MWB	MBB	MBB	MWW
24		7	MBW	HBG	HWB	HWB	LBW	HWW
28		7	LBW	LWB	MBW	HBB	HBB	LGB
14		9	MBA	HWB	HBW	HWB	HWB	HWW
20		9	HWA	HWB	LWA	MWA	MBW	MGB
5		10	LBA	MBW	MBW	HWB	HWB	LBB
27		12	MGB	MGB	MBG	LWB	LWB	HBG
39		12	HGW	LWB	LBW	LBB	LBB	HBG
32		13	HBW	HBG	HWB	HBB	HBB	HWW
19		14	MWA	HWB	HWB	HBW	HWB	HWW
6		16	MBG	MBG	LGB	MBW	MWB	MGW
7		16	MBA	MWB	MBA	MBW	MWB	MBW

* H = high; M = medium; L = low; N = none; B = broadleaf; G = grass; W = woody, A = absent.

Treatment plots were classified as having low levels to no vegetation present with broadleaf, grass and woody species (Table 6). Low vegetation levels constituted 30 out of 40 treatment plots (75%). In the thinned treatment plots, four visual codes were assigned. Seven treatment plots were classified as NAA, six as LBA, three as LBG and one as LWA. There were eight visual codes representing unthinned treatment plots. LBA had the highest occurrences in the unthinned stands, with nine treatment plots. There was one plot each classified as LBB and LWA, two plots assigned LBG, LWB and LWG and three plots described as LGA and NAA. The remaining ten treatment plots (25%) were NAA, with no vegetation present. LBA was the most frequent observation representing 15 out of 40 (37.5%) treatment plots. No vegetation, or the absent category, was applied the most frequently for vegetation type. Broadleafs were the most common surveyed vegetation type followed by grass and woody.

Control plots had high, medium, low and none UCV levels; all three vegetation types were represented (Table 6). Unthinned control plots had 12 visual codes. HWW was the most common visual code with a total of eight. Next were HBG, HWB, MBW and MGB each with two unthinned control plots. Lastly, HBB, MGW, MWB, MWW, LBB, LGB and LWB all occurred in one unthinned control plot. Thinned control plots covered ten visual codes. Four thinned control plots were HWW, the most common. HBG and HWB each occurred three times. All others, HGW, HWG, MBG, MWW, LBW, LGB and NAA, occurred once each. Overall, high UCV levels accounted for 62.5 percent of the control plots, medium 22.5 percent and low 12.5 percent. One location had no living plants (none) due to a recent aerial herbicide application prior to the assessment and constituted two and half percent of the control plots

Table 6: Number of control plots from the September 2013 visual assessment at Hofmann Forest, NC. Visual code refers to the visual assessment code. Treatment is the plot, receiving optimum fertilization and complete vegetation control. Control is the plot receiving operational fertilization and vegetation control. These results are used in the analysis where corresponding measurements were made.

Visual Code*	Treatment Thinned	Treatment Unthinned	Totals
LBA	6	9	**15**
NAA	7	3	**10**
LBG	3	2	**5**
LGA	---	3	**3**
LWB	---	2	**2**
LWG	---	2	**2**
LWA	1	1	**2**
LBB	---	1	**1**
Totals	**17**	**23**	**40**

Visual Code*	Control Thinned	Control Unthinned	Totals
HWW	4	8	**12**
HBG	3	2	**5**
HWB	3	2	**5**
MBW	---	2	**2**
MGB	---	2	**2**
MWW	1	1	**2**
LGB	1	1	**2**
HBB	---	1	**1**
MGW	---	1	**1**
MWB	---	1	**1**
LBB	---	1	**1**
LWB	---	1	**1**
NAA	1	---	**1**
HGW	1	---	**1**
HWG	1	---	**1**
MBG	1	---	**1**
LBW	1	---	**1**
Totals	**17**	**23**	**40**

* H = high; M = medium; L = low; N = none; B = broadleaf; G = grass; W = woody, A = absent.

The dominant UCV type observed in the control plots was absent, grass, broadleaf and woody in 1, 6, 11 and 22 control plots, respectively. The dominant vegetation type was then categorized by each competing vegetation level, for thinned and unthinned stands, to see where each vegetation type occurred (Figure 7). The co-dominant competing vegetation types are not discussed here. Out of 25 high level control plots, 18 had woody species as the dominant vegetation type; eight were thinned and ten were unthinned. Three broadleaf species were found in thinned and unthinned high level control plots each, six broadleaf in high control plots. A grass species was only found in one high level thinned control plot. For medium level plots, thinned stands had one broadleaf and one woody control plot. There were two unthinned medium control plots each, one with broadleaf and the other with woody vegetation types. Grass dominated in three unthinned control plots with medium vegetation level. Of the five low level control plots, two were thinned and three were unthinned. The two thinned low level control plots were broadleaf and grass vegetation dominated. The three unthinned low level control plots had broadleaf, grass and woody vegetation types. Only one control plot was characterized as none with absent vegetation. This stand had been thinned.

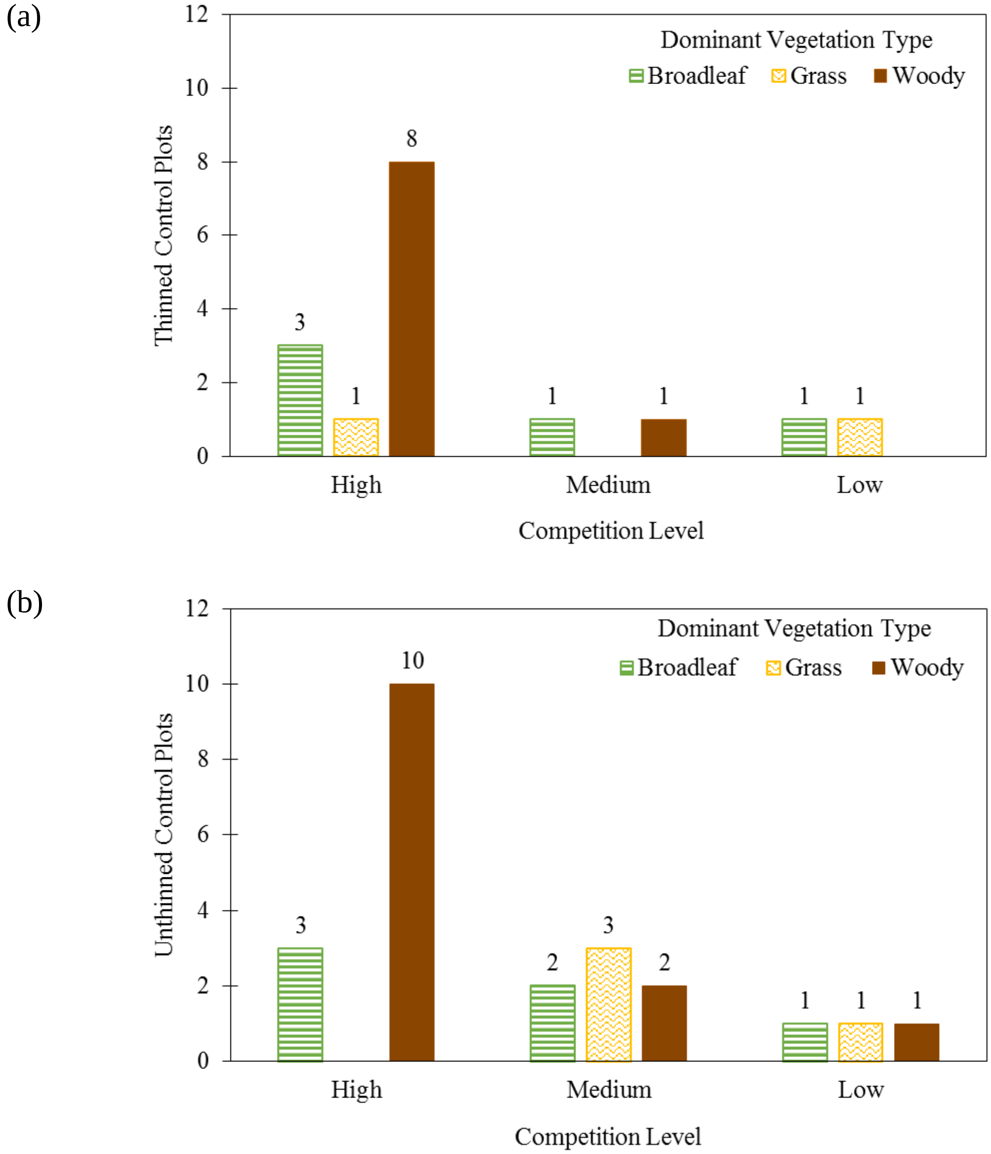


Figure 7: Dominant competing vegetation type in thinned (a) and unthinned (b) control plots for each understory competing vegetation level at Hofmann Forest, NC in September 2013. Solid brown bars represent woody vegetation, green stripes are broadleaf species and yellow wavy lines are grass species. The number above each bar is the number of the control plots. Not all vegetation types were observed for each level and thinning. One thinned control plot had no living understory vegetation (none-absent) and was omitted here.

UCV level and the dominant vegetation type relative frequencies are shown in Table 7. The relative frequency refers to the number of control plots and the percent frequency of each association. The percent frequency, in italics, was calculated by the control plot count (cells) ratio to the total number of control plots (39). Twin plot three with no vegetation was omitted from this analysis. The strongest association between level and dominant vegetation type was high and woody control plots at 46 percent. High and broadleaf control plots also had an association, a different relative frequency, worth noting at 15 percent. Little to no association exists between the other types and levels because the relative frequencies are not different from at least one other combination. The interaction between the level and competing vegetation type could not be tested using Chi Square, because more than one expected frequencies was less than five. Therefore, an appropriate test of significance could not be conducted.

Table 7: Contingency table to present the association between the dominant competing vegetation level and type. Values indicate the count of control plots. Percentages are the relative frequencies of level and type compared to the total number of control plots (39). Totals are the summation for each row or column. The twin plot with no vegetation was omitted from analysis. Levels and dominant vegetation type were determined in September 2013 at Hofmann Forest, NC.

Level of Competition	**Dominant Vegetation Type**			**Totals**
	Broadleaf	**Grass**	**Woody**	
High	6	1	18	**25**
	15%	*3%*	*46%*	*64%*
Medium	3	3	3	**9**
	8%	*8%*	*8%*	*23%*
Low	2	2	1	**5**
	5%	*5%*	*3%*	*13%*
Totals	**11**	**6**	**22**	**39**
	28%	*15%*	*56%*	*100%*

1.4.2 Visual Assessment on Mineral and Organic Soils

The UCV level varied across a range of mineral and organic soils. There were 20 twin plots with mineral and 20 with organic soils. Each control plot was graphed based on the soil characteristics, the competition level, vegetation type and thinning (Figure 8). Here, the soil type is expressed as the percent of organic matter (carbon) found within the top 0-40 centimeters of the surface horizon. The percent organic matter is used, because the soil type transitions across Hofmann Forest depending on the distance from pocosin. Twin plots in close approximation to the pocosin have a thick, mucky organic layer overlaying mineral deposits. The organic layer decreases and transitions into predominately mineral soils the further away from the pocosin, but there is not a clear boundary between the two soil types. The percent of carbon was previously determined by a complete soil nutritional analysis up to 100 centimeters (Appendix B) (FPC, 2013). Along the horizontal axis in Figure 8, there is a division between the organic and mineral soil types, illustrated by the vertical line. All plots containing less than 9.42 percent of carbon are mineral soils, including Ultisols, Spodosols and one Inceptisol. All control plots containing greater than 9.42 percent carbon are organic soils, Histosols. Each point represents one control plot. The UCV level can be found along the vertical axis. Only one control plot had the none level; a thinned stand with mineral soil. The vegetation type is represented by the color and shape of each point. Green circles are for broadleaf species, yellow triangles for grass and brown squares are for woody vegetation types. In an effort to simplify the results, the co-dominant vegetation types are not included here.

The dominant vegetation types occurred over different ranges of average percent carbon in the top 40 centimeters of the soil profile. Broadleaf vegetation ranged from 5.8 to 21.0 percent average carbon, almost equally distributed across the range of soil type (6 mineral and 5 organic). Dominant grass species were predominantly present on organic soils (2 mineral and 4 organic) but had a range of 5.5 to 13.9 average percent carbon. Woody dominant species were observed over the largest range of soil types; 2.6 to 26.9 average percent carbon with even amounts of mineral and organic soils (11 each).

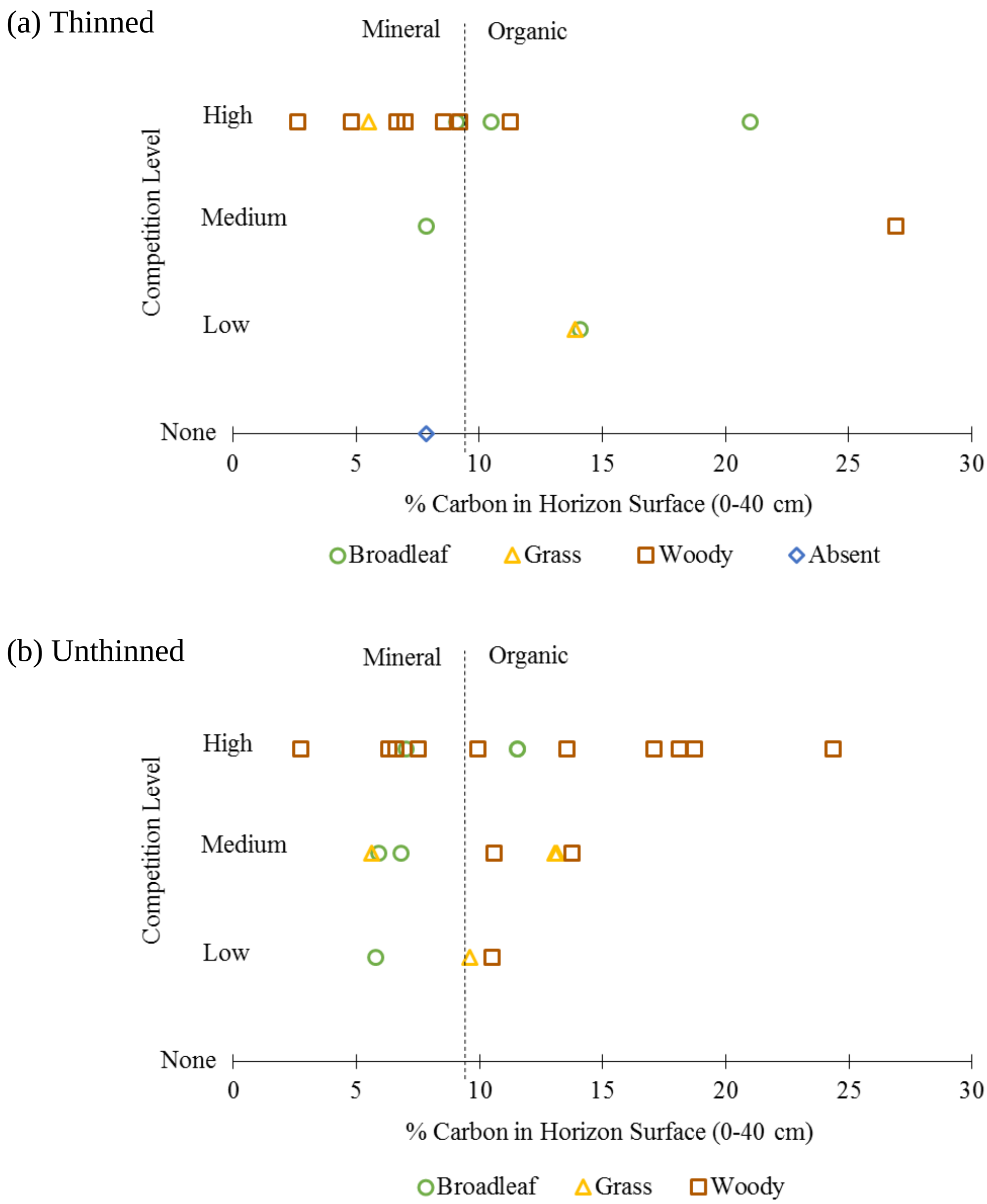


Figure 8: The competing vegetation level by the soil type, mineral or organic, in thinned (a) and unthinned (b) control plots at Hofmann Forest, NC in September 2013. The vegetation type is shown by the shape and color of each point. Broadleafs are shown as green circles, grass vegetation as yellow triangles and woody vegetation as brown squares. Soil is expressed as the average percent of carbon (organic matter) in the top 40 centimeters. Mineral soils and organic soils are divided by the vertical line at 9.42 percent carbon.

There were 14 high level control plots with mineral soils compared to 11 control plots with organic soil (Table 8). Medium control plots had four plots with mineral soil and five with organic. Low plots had one with mineral and four with organic soil. Considering only the dominant UCV type in thinned stands, there were two broadleaf, one grass and seven woody control plots with mineral soils compared to three broadleaf, one grass and two woody control plots with organic soils. Dominant UCV type in unthinned stands with mineral soils had four broadleaf, one grass and four woody control plots compared to two broadleaf, three grass and nine woody control plots in organic soils. One thinned twin plot, with mineral soil, received an additional herbicide treatment, causing it to have no living competing vegetation, and was not included here.

Table 8: The number of thinned or unthinned control plots by dominant competing vegetation type for each vegetation level in either organic or mineral soil. One control plot, in mineral soil, was omitted because it had no living vegetation. Analysis was conducted at Hofmann Forest, NC in September 2013.

		Competing Vegetation Level							
		Low		**Medium**		**High**		**Totals**	
		Mineral	**Organic**	**Mineral**	**Organic**	**Mineral**	**Organic**	**Mineral**	**Organic**
Thinned	**Broadleaf**	---	1	1	---	1	2	**2**	**3**
	Grass	---	1	---	---	1	---	**1**	**1**
	Woody	---	---	---	1	7	1	**7**	**2**
Unthinned	**Broadleaf**	1	---	2	---	1	2	**4**	**2**
	Grass	---	1	1	2	---	---	**1**	**3**
	Woody	---	1	---	2	4	6	**4**	**9**
	Totals	**1**	**4**	**4**	**5**	**14**	**11**	**19**	**20**

1.4.3 Species Characterization

Twenty three species (Table 9) were identified as the dominant or co-dominant species in the 40 control plots at Hofmann Forest. Seventeen plant families were represented. Four families, Aquifoliaceae, Asteraceae, Poaceae and Smilacaeae, had more than one species within the family. All but one species was perennial; American burnweed is an annual forb/herb. All the species found are native to North Carolina. Only the common names listed by the USDA PLANTS Database are listed in Table 9 (USDA NRCS, *available online*).

Table 9: Lists the dominant and co-dominant species observed in the control plots at Hofmann Forest, NC during the 2013 growing season. The list is arranged from the species most frequently observed in the control plots, as either dominant or co-dominant, to the least commonly observed. Type refers to the category from the visual assessment.

Dominant and Co-dominant Species	Common Name	Family	Type*	Growth Habit**	Total
Eupatorium capillifolium (Lam.) Small	dogfennel	Asteraceae	B	Forb/herb	8
Ilex coriacea (Pursh) Chapm.	large gallberry	Aquifoliaceae	W	Shrub, Tree	8
Rubus sp. L.	blackberry	Rosaceae	W	Shrub, Subshrub	6
Pinus taeda L.	loblolly pine	Pinaceae	W	Tree	5
Acer rubrum L.	red maple	Aceraceae	W	Tree	8
Dichanthelium commutatum (Schult.) Gould	variable panicgrass	Poaceae	G	Graminoid	6
Pteridium aquilinum (L.) Kuhn	western brackenfern	Dennstaedtiaceae	B	Forb/herb	4
Persea palustris (Raf.) Sarg.	swamp bay	Lauraceae	W	Shrub, Tree	3
Carex glaucescens Elliott	southern waxy sedge	Cyperaceae	G	Graminoid	2
Smilax glauca Walter	cat greenbrier	Smilacaceae	B	**Vine**, Shrub	4
Aralia spinosa L.	devil's walkingstick	Araliaceae	W	Tree, Shrub	3
Cyrilla racemiflora L.	swamp titi	Cyrillaceae	W	Shrub, Tree	3
Lyonia lucida (Lam.) K. Koch	fetterbush lyonia	Ericaceae	W	Shrub	3
Andropogon virginicus L.	broomsedge bluestem	Poaceae	G	Graminoid	3
Arundinaria gigantea (Walter) Muhl.	giant cane	Poaceae	G	**Graminoid**, Shrub, Subshrub	2
Smilax laurifolia L.	laurel greenbrier	Smilacaceae	B	**Vine**, Shrub	2
Gordonia lasianthus (L.) Ellis	loblolly bay	Theaceae	W	Shrub, Tree	1
Erechtites hieraciifolius (L.) Raf.ex DC	American burnweed	Asteraceae	B	Forb/herb	2
Toxicodendron radicans (L.) Kuntze	eastern poison ivy	Anacardiaceae	B	**Forb/herb, Vine**, Shrub	1
Ilex opaca Aiton	American holly	Aquifoliaceae	W	Shrub, Tree	1
Solidago sp. L.	goldenrod	Asteraceae	B	Forb/herb	1
Gelsemium sempervirens (L.) W.T. Aiton	evening trumpetflower	Loganiaceae	B	**Vine**, Shrub	1
Vitis rotundifolia Michx.	muscadine	Vitaceae	B	Vine	1

* B = broadleaf; G = grass; W = woody.

**Bold words are the growth habit observed at Hofmann Forest.

Plant species from each UCV type were identified. The nine broadleaf species were eastern poison ivy, American burnweed, dogfennel, goldenrod, western brackenfern, evening trumpetflower, cat greenbrier, laurel greenbrier and muscadine. The four grass species were southern waxy sedge, broomsedge bluestem, giant cane and variable panicgrass. The ten woody species were red maple, large gallberry, American holly, devil's walking stick, swamp titi, fetterbush lyonia, swamp bay, loblolly pine, blackberry and loblolly bay.

Of the 23 species, 11 are intolerant of shade and generally respond well to disturbance: devil's walkingstick, American burnweed, dogfennel, goldenrod, western brackenfern, evening trumpetflower, broomsedge bluestem, giant cane, blackberry, cat greenbrier, laurel greenbrier. Moderately (intermediate) tolerant species, somewhat resistant of disturbance, were red maple, eastern poison ivy, southern waxy sedge, swamp titi, fetterbush lyonia, swamp bay, loblolly pine and muscadine; a total of eight species. Four species are tolerant to shade and not resistant to disturbance: large gallberry, American holly, swamp bay, variable panicgrass, loblolly bay.

Since each plant species responds differently to light and disturbances, thinning affects the presence of dominant and co-dominant UCV species. Thinning operations were conducted in 17 stands at Hofmann Forest, NC by the time of analysis. Thinning was 4^{th} row harvest with additional selection cuts in remaining rows. Table 10 shows a detailed description of stand and environmental attributes (thinning date; age; soil description) of thinned control plots and the associated species. The table is sorted with the most recent thinning first to show species succession after a disturbance caused from thinning. The stand age in 2013 is shown. The soil profile, seasonal water table and results from the visual assessment are also listed.

Unthinned stands are generally younger stands where the trees have not reached a size to warrant operational thinning. There were 23 thinned stands in September 2013. Table 11 provides site specific information about the stand environment in the unthinned stands, sorted from youngest to oldest. Younger stands are in an earlier stage of succession and will have different vegetation than older stands. The soil order, soil series and seasonal water table is provided. The results from the visual assessment are listed.

Table 10: Description of stand attributes in thinned twin plots at Hofmann Forest; year of thinning, stand age in 2013, soil order and series, seasonal water table, assigned visual assessment code for treatment and control plots, and the dominant and co-dominant species. The table is sorted by from the most recent thinning to the oldest to show how recently a disturbance from thinning occurred.

Twin Plot	Thinning Date	Age (2013)	Soil Taxonomy (Order)	Map Unit (Series)*	Seasonal Water Table (cm)	Visual Assessment Treatment**	Visual Assessment Control **	Control Dominant Species	Control Co-Dominant Species
17	2013	14	Histosol	Ct	>100	LBG	LGB	*Dichanthelium commutatum*	*Pteridium aquilinum*
21	2013	10	Histosol	Ct	>100	NAA	LBW	*Smilax glauca*	*Rubus sp.*
25	2012	12	Histosol	To	>100	LBG	HBG	*Eupatorium capillifolium*	*Dichanthelium commutatum*
29	2012	10	Inceptsol	To	>100	LBA	HBG	*Eupatorium capillifolium*	*Dichanthelium commutatum*
23	2012	14	Spodosol	Pn	>100	LBA	MBG	*Eupatorium capillifolium*	*Andropogon virginicus*
11	2010	15	Histosol	Pn	85	NAA	MWW	*Rubus sp.*	*Aralia spinosa*
34	2008	19	Spodosol	To	30	NAA	HWB	*Cyrilla racemiflora*	*Smilax glauca*
40	2008	23	Spodosol	To	60	NAA	HGW	*Andropogon virginicus*	*Acer rubrum*
37	2007	23	Histosol	Ct	90	LBG	HBG	*Eupatorium capillifolium*	*Andropogon virginicus*
36	2007	23	Spodosol	Ct	60	LBA	HWW	*Pinus taeda*	*Ilex coriacea*
18	2006	19	Histosol	Ct	90	NAA	HWB	*Pinus taeda*	*Eupatorium capillifolium*
3	2006	18	Spodosol	Ct	98	NAA	NAA	Absent	Absent
1	2005	21	Ultisol	Pn	75	LBA	HWW	*Pinus taeda*	*Acer rubrum*
31	2004	24	Spodosol	To	>100	NAA	HWW	*Persea palustris*	*Acer rubrum*
13	2004	21	Ultisol	Pn	90	LWA	HWW	*Pinus taeda*	*Ilex coriacea*
8	2003	21	Ultisol	Ra	88	LBA	HWB	*Acer rubrum*	*Pterifium aquilinum*
9	2003	21	Ultisol	Ra	>>100	LBA	HWG	*Acer rubrum*	*Arundinaria gigantea*

*Ct – Croatan Muck; Pn — Pantego mucky loam or loam; Ra – Rains fine sandy loam; To – Torhunta fine sandy loam.
** H = high; M = medium; L = low; N = none; B = broadleaf; G = grass; W = woody, A = absent.

Table 11: Description of stand attributes in unthinned twin plots at Hofmann Forest; stand age in 2013, soil order and series, seasonal water table, the assigned visual assessment code for treatment and control plots and the dominant and co-dominant species. Information is sorted from the youngest stand to the oldest.

Twin Plot	Age (2013)	Soil Taxonomy (Order)	Map Unit (Series)*	Seasonal Water Table (cm)	Visual Assessment Treatment**	Visual Assessment Control**	Control Dominant Species	Control Co-Dominant Species
22	4	Histosol	Ct	70	LBB	HWB	*Ilex coriacea*	*Solidago sp.*
33	4	Histosol	Ct	80	LWG	HWB	*Ilex coriacea*	*Smilax laurifolia*
35	4	Spodosol	Pn	55	LWB	HBB	*Smilax laurifolia*	*Smilax glauca*
2	4	Ultisol	Pn	>100	LWB	HWW	*Rubus sp.*	*Lyonia lucida*
15	5	Histosol	Pn	65	LWG	MGB	*Carex glaucescens*	*Erechtites hieraciifolius*
30	5	Histosol	To	50	LWA	HWW	*Gordonia lasianthus*	*Cyrilla racemiflora*
4	5	Ultisol	Ra	98	LBA	MBW	*Eupatorium capillifolium*	*Rubus sp.*
26	6	Histosol	To	>100	LBA	LWB	*Rubus sp.*	*Gelsemium sempervirens*
38	6	Histosol	Ct	>>100	NAA	MWB	*Rubus sp.*	*Smilax glauca*
16	6	Ultisol	Pn	60	LGA	HWW	*Ilex coriacea*	*Persea palustris*
12	7	Histosol	Pn	>100	NAA	MWW	*Ilex coriacea*	*Cyrilla racemiflora*
28	7	Histosol	Ct	>100	LGA	LGB	*Dichanthelium commutatum*	*Vitis rotundifolia*
24	7	Spodosol	To	40	NAA	HWW	*Ilex coriacea*	*Aralia spinosa*
10	7	Ultisol	Ra	>100	LBA	HWW	*Aralia spinosa*	*Ilex opaca*
14	9	Histosol	Pn	65	LBA	HWW	*Ilex coriacea*	*Acer rubrum*
20	9	Histosol	Pn	>100	LBA	MGB	*Carex glaucescens*	*Erechtites hieraciifolius*
5	10	Ultisol	Ra	>100	LBA	LBB	*Pteridium aquilinum*	*Toxicodendron radicans*
27	12	Histosol	Ct	>100	LBG	HBG	*Eupatorium capillifolium*	*Dichanthelium commutatum*
39	12	Histosol	Ct	>>100	LGA	HBG	*Eupatorium capillifolium*	*Dichanthelium commutatum*
32	13	Histosol	Ct	85	LBG	HWW	*Lyonia lucida*	*Acer rubrum*
19	14	Histosol	Pn	>100	LBA	HWW	*Persea palustri*	*Lyonia lucida*
6	16	Ultisol	Ra	>100	LBA	MGW	*Arundinaria gigantea*	*Pinus taeda*
7	16	Ultisol	Ra	>100	LBA	MBW	*Pteridium aquilinum*	*Acer rubrum*

*Ct – Croatan Muck; Pn — Pantego mucky loam or loam; Ra – Rains fine sandy loam; To – Torhunta fine sandy loam.
** H = high; M = medium; L = low; N = none; B = broadleaf; G = grass; W = woody, A = absent.

Dogfennel and large gallberry were found most frequently as the dominant vegetation in a total of seven and six control plots, respectively. Blackberry and volunteer loblolly pine were each identified in four control plots. Red maple, variable panicgrass, western brackenfern, swamp bay and southern waxy sedge were the dominant vegetation in two control plots each. The least commonly observed species were cat greenbrier, devil's walking stick, swamp titi, fetterbush lyonia, broomsedge bluestem, giant cane, laurel greenbrier and loblolly bay each occurred in only one control plot. The frequency of co-dominant vegetation species can be found in Appendix F. The following species were only found as co-dominant species: American burnweed, poison ivy, American holly, goldenrod, evening trumpetflower and muscadine (grape) vine.

The dominant species identified in the thinned versus unthinned control plots varied (Table 12). The following species were found in both thinned and unthinned control plots: dogfennel, western brackenfern, cat greenbrier, variable panicgrass, giant cane, loblolly pine, red maple, large gallberry, swamp titi, swamp bay, devil's walking stick and blackberry. Broomsedge bluestem was only found in thinned control plots. Laurel greenbrier, southern waxy sedge, loblolly bay and fetterbush lyonia were only found in unthinned control plots. Six co-dominant species, evening trumpetflower, eastern poison ivy, goldenrod, American burnweed, muscadine and American holly, were only found in unthinned stands (Appendix F).

Table 12: Dominant species total frequency by the competing vegetation level, in thinned versus unthinned control plots at Hofmann Forest, NC in September 2013. Each value represents the number of control plots. Frequency refers to the total occurrences of each dominant species sorted by the most commonly identified in a control plot to the least common. Totals can be found in the last row and column. One twin plot was absent of vegetation and was not included here.

	Level of Competition			
Thinned Control Dominant Species	**Low**	**Medium**	**High**	**Totals**
Eupatorium capillifolium	- - -	1	3	**4**
Pinus taeda	- - -	- - -	4	**4**
Acer rubrum	- - -	- - -	2	**2**
Andropogon virginicus	- - -	- - -	1	**1**
Cyrilla racemiflora	- - -	- - -	1	**1**
Dichanthelium commutatum	1	- - -	- - -	**1**
Persea palustris	- - -	- - -	1	**1**
Rubus sp.	- - -	1	- - -	**1**
Smilax glauca	1	- - -	- - -	**1**
Totals	**2**	**2**	**12**	**16**
Unthinned Control Dominant Species	**Low**	**Medium**	**High**	**Totals**
Ilex coriacea	- - -	1	5	**6**
Eupatorium capillifolium	- - -	1	2	**3**
Rubus sp.	1	1	1	**3**
Carex glaucescens	- - -	2	- - -	**2**
Pteridium aquilinum	1	1	- - -	**2**
Aralia spinosa	- - -	- - -	1	**1**
Arundinaria gigantea	- - -	1	- - -	**1**
Dichanthelium commutatum	1	- - -	- - -	**1**
Gordonia lasianthus	- - -	- - -	1	**1**
Lyonia lucida	- - -	- - -	1	**1**
Persea palustris	- - -	- - -	1	**1**
Smilax laurifolia	- - -	- - -	1	**1**
Totals	**3**	**7**	**13**	**23**
Thinned and Unthinned Totals	**5**	**9**	**25**	**39**

When control plots were thinned and a high amount of broadleaf vegetation was found, the dominant species were dogfennel, cat greenbrier and western brackenfern (Table 13). Thinned high vegetation control plots with grasses consisted of variable panicgrass, broomsedge bluestem and giant cane. High woody thinned control plots were dominated by red maple, swamp titi, swamp bay, large gallberry and loblolly pine. There were two medium level thinned control plots; one had broadleaf (dogfennel) and grass (broomsedge bluestem) species, and the other had two woody species, blackberry and devil's walking stick. For the two low level thinned control plots, broadleaf species were cat greenbrier and western brackenfern, grass species was variable panicgrass and the woody species was blackberry. One thinned control plot was classified as having no living vegetation due to herbicide.

When control plots were not thinned and had a high amount of broadleaf vegetation, laurel greenbrier, cat greenbrier, goldenrod and dogfennel dominated (Table 13). The one high level unthinned stand with grass had variable panicgrass. Unthinned stands with high levels and woody vegetation included large gallberry, blackberry, devil's walking stick, fetterbush lyonia, swamp bay, loblolly bay, red maple, American holly and swamp titi. Unthinned medium plots had four dominant broadleaf species, dogfennel, western brackenfern, American burnweed and cat greenbrier. Two grass species, southern waxy sedge and giant cane, dominated three medium unthinned control plots. Woody species found in medium level unthinned plots included red maple, blackberry, loblolly pine, large gallberry and swamp titi. Broadleaf species were found in the three low level unthinned control plots, western brackenfern, eastern poison ivy, muscadine and evening trumpetflower. Low level unthinned plots had one grass species, variable panicgrass, and one woody species, blackberry.

The overall biodiversity of Hofmann Forest control plots can be found in Table 14. The species are listed according to the vegetation type, broadleaf, grass or woody, identified during the visual assessment. Species frequency of occurrences for UCV species is expressed as the percent of control plots containing at least one species individual. Dominant and co-dominant species are grouped here. Then the competition level, where each species was found, is expressed as the percent of occurrences in each level, low, medium or high.

Table 13: The dominant and co-dominant species identified in control plots, in both thinned and unthinned twin plots, by the visual assessment code conducted at Hofmann Forest during the 2013 growing season. The number in parenthesis beside each name is the number of control plots where species was dominant or co-dominant.

Thinned

Code*	Count	Dominant Species	Co-Dominant Species
HBG	3	*Eupatorium capillifolium* (3)	*Dichanthelium commutatum* (2), *Andropogon virginicus* (1)
HGW	1	*Andropogon virginicus* (1)	*Acer rubrum* (1)
HWB	3	*Cyrilla racemiflora* (1), *Pinus taeda* (1), *Acer rubrum* (1)	*Smilax glauca* (1), *Eupatorium capillifolium* (1), *Pterifium aquilinum* (1)
HWG	1	*Acer rubrum* (1)	*Arundinaria gigantea* (1)
HWW	4	*Pinus taeda* (3), *Persea palustris* (1)	*Ilex coriacea* (2), *Acer rubrum* (2)
MBG	1	*Eupatorium capillifolium* (1)	*Andropogon virginicus* (1)
MWW	1	*Rubus sp.* (1)	*Aralia spinosa* (1)
LBW	1	*Smilax glauca* (1)	*Rubus sp.* (1)
LGB	1	*Dichanthelium commutatum* (1)	*Pteridium aquilinum* (1)
NAA	1		

Unthinned

Code*	Count	Dominant Species	Co-Dominant Species
HBB	1	*Smilax laurifolia* (1)	*Smilax glauca* (1)
HBG	2	*Eupatorium capillifolium* (2)	*Dichanthelium commutatum* (2)
HWB	2	*Ilex coriacea* (2)	*Solidago sp.* (1), *Smilax laurifolia* (1)
HWW	8	*Rubus sp.* (1), *Ilex coriacea* (3), *Aralia spinosa* (1), *Lyonia lucida* (1), *Persea palustris* (1) *Gordonia lasianthus* (1),	*Acer rubrum* (2), *Ilex opaca* (1), *Aralia spinosa* (1), *Lyonia lucida* (2), *Persea palustris* (1), *Cyrilla racemiflora* (1)
MBW	2	*Eupatorium capillifolium* (1), *Pteridium aquilinum* (1)	*Acer rubrum* (1), *Rubus sp.* (1)
MGB	2	*Carex glaucescens* (2)	*Erechtites hieraciifolius* (2)
MGW	1	*Arundinaria gigantea* (1)	*Pinus taeda* (1)
MWB	1	*Rubus sp.* (1)	*Smilax glauca* (1)
MWW	1	*Ilex coriacea* (1)	*Cyrilla racemiflora* (1)
LBB	1	*Pteridium aquilinum* (1)	*Toxicodendron radicans* (1)
LGB	1	*Dichanthelium commutatum* (1)	*Vitis rotundifolia* (1)
LWB	1	*Rubus sp.* (1)	*Gelsemium sempervirens* (1)

* H = high; M = medium; L = low; N = none; B = broadleaf; G = grass; W = woody, A = absent.

Table 14: Biodiversity of competing vegetation species identified in the control plots at Hofmann Forest, NC in September 2013. Species are listed by the vegetation type. Frequency, expressed as a percent, is the occurrences of each species found in control plots containing at least one individual. Dominant and co-dominant species are grouped here. Species by level is the percentage of control plots, for each species, to show the competition level where the species occurred.

Type of Vegetation	Frequency (%)	Species by Level (%)		
		Low	Medium	High
Broadleaf Species				
Eupatorium capillifolium	20	88	0	13
Pteridium aquilinum	10	50	25	25
Smilax glauca	10	25	25	50
Smilax laurifolia	5	0	0	100
Erechtites hieraciifolius	5	0	100	0
Toxicodendron radicans	2.5	100	0	0
Solidago sp.	2.5	0	0	100
Gelsemium sempervirens	2.5	100	0	0
Vitis rotundifolia	2.5	100	0	0
Grass Species				
Dichanthelium commutatum	15	33	0	67
Andropogon virginicus	7.5	0	33	67
Carex glaucescens	5	0	100	0
Arundinaria gigantea	5	0	50	50
Woody Species				
Ilex coriacea	20	0	13	88
Acer rubrum	20	0	13	88
Rubus sp.	15	33	50	17
Pinus taeda	12.5	0	20	80
Persea palustris	7.5	0	0	100
Aralia spinosa	7.5	0	33	67
Cyrilla racemiflora	7.5	0	33	67
Lyonia lucida	7.5	0	0	100
Gordonia lasianthus	2.5	0	0	100
Ilex opaca	2.5	0	0	100

Four control plots had a distinct volunteer loblolly pine understory cover creating a secondary pine canopy. These four plots had been thinned at least six years prior to the assessment and were around 20 years old in 2013 (Table 15). The co-dominant species were large gallberry (woody shrub), red maple (tree) and dogfennel (broadleaf). Three out of four sites had mineral soils; the other was a Histosol, rich in organic matter. The water table for these four sites ranged from 60-90 centimeters.

Table 15: Stand attributes for control plots with a strong presence of volunteer loblolly pine in the understory at Hofmann Forest, NC in 2013.

Age (2013)	Years Since Thinning	Co-Dominant Species	Soil Taxonomy (Order)	Map Unit (Series)*	Horizon Surface Textural Class (0-40 cm)	Horizon Subsurface Textural Class (80-100 cm)	Seasonal Water Table (cm)
23	6	*Ilex coriacea*	Spodosol	Ct	mucky + litter	sand	60
21	8	*Acer rubrum*	Ultisol	Pn	loam	sandy clay loam	75
21	9	*Ilex coriacea*	Ultisol	Pn	loam	sandy clay loam	90
19	7	*Eupatorium capillifolium*	Histosol	Ct	muck	sandy loam	90

*Ct – Croatan Muck; Pn – Pantego loam.

1.5 Conclusion

The understory competing vegetation (UCV) on midrotation loblolly pine plantations at Hofmann Forest is diverse in vegetation level and type. Others have reported diverse and abundant understory communities, over a range of treatments, in the North Carolina Coastal Plain (Lane et al. 2011). The September 2013 visual assessment had eight visual code combinations in the treatment plots (high intensity treatments) compared to 17 in the control plots (low intensity treatments). The UCV level and dominant vegetation in the treatment plots was typically low-broadleaf-absent (LBA) or none-absent-absent (NAA). The additional vegetation management, conducted by FPC in the treatment plots, is maintaining low to none vegetation levels in both thinned and unthinned stands. The continued vegetation control is suppressing the competition.

Within the control plots, high-woody-woody (HWW) was the most common occurrences (14 of the 40 control plots) found in thinned and unthinned stands. High-woody-broadleaf (HWB) and high-broadleaf-grass (HBG) were also commonly found. High-woody (HW) control plots made up 46 percent and high-broadleaf (HB) 15 percent of all the control plots. Broadleaf and grass vegetation are shaded out as loblolly pine canopy develops. Woody, shade tolerant species thrive under closed canopies. Midrotation understory vegetation appears to be predominantly influenced by successional dynamics associated with pine canopy closure, despite differences in establishment treatments (Jefferies et al. 2010; Campbell et al. 2015).

The variations in vegetation levels, or percent cover, are similar to observations by others. Lane et al. (2011) reports high intensity establishment practices had lower vegetation cover and was less diverse than the lower intensity treatments. Peduzzi et al. (2010) visually estimated understory coverage on seven and ten year old flatwood loblolly stands, with poorly drained Spodosols and Ultisols, to be 53 and 67.8 percent, respectively. Compared to the percent covers used in this visual assessment, these stands would have high vegetation levels at rotation age seven and ten years. Peduzzi et al. (2010) also reported a high range of loblolly pine understory coverage (25 to 95%), both extremes on two, seven year old somewhat poorly drained plots.

Surprisingly, soil type did not provide a clear indication of vegetation type or level at Hofmann Forest, as expected. High level control plots, the most common UCV situation, occurred on 14 mineral and 11 organic sites. Woody vegetation had equal numbers of mineral and organic sites, 11 control plots each. Vegetation on pocosin sites are highly affected by the depth to water table. Drainage at Hofmann could be equalizing the water table depth and therefore the vegetative community. The fertilization of N and P could also be correcting possible nutrient deficiencies.

The observed dominant and co-dominant species were expected. The species were consistent with what others have found in Pocosin and other Coastal Plain locations across the SEUS in loblolly pine plantations (Wells 1928; Stransky et al. 1986; Christensen et al. 1988; Oppenheimer et al. 1989; Neary et al. 1990; Zutter and Miller, 1998; Miller et al. 2003a; Martin and Jokela, 2004; Lane et al. 2011; Campbell et al. 2015). *Eupatorium capillifolium* (dogfennel) was the most commonly identified dominant species and was present in thinned and unthinned stands, at medium to high vegetation levels on mineral and organic soils, over varying ages. Dogfennel is generally intolerant of closed or highly structured communities and is considered an early seral species, in some cases, an invader (USDA NRCS, *available online*). Hurricane damage, pine mortality and management activities can cause enough disturbance to open the canopy, promoting dogfennel growth.

Ilex coriacea (large gallberry), an evergreen woody shrub, was the second most common dominant species on six unthinned control plots, predominantly at high levels, on mineral and organic soils. Gallberry is a mid to late seral species, grows well under a mature forest canopy and does not respond well to disturbances (USDA NRCS, *available online*). When gallberry was present, it had a strong dominance of growing space. In a midrotation pine vegetation control, fertilization and combined treatments study, two years after these treatments the evergreen shrub community was reduced 51 percent but recovered to 80 percent greater than the pretreatment amount in eight years for the vegetation control plots (Albaugh et al. 2012b). In the northwest, Suchar and Crookston (2010) observed shrub percent cover was significantly influenced by disturbance time and type, and the soil characteristics.

Typically, vegetation control methods temporarily suppress unwanted competing vegetation present in midrotation loblolly pine plantations. Visual assessments after a thinning show low vegetation levels with broadleafs and grasses. However, some thinned stands had a quick recovery of woody species, such as volunteer *Pinus taeda* (loblolly pine) and *Acer rubrum* (red maple), explained by resiliency to disturbance and undamaged viable rootstocks. Loblolly responds well to disturbance and thinning promotes volunteer regrowth. Red maple is a rapidly growing hardwood, performing well under a range of light environments. Overall, a greater number of species were identified in unthinned stands, but there were six more unthinned than thinned control plots. A possible explanation for the greater species numbers could be because a longer period has transpired since the last disturbance, allowing mid- and/or late-seral species to proliferate. Thinned stands have had a more recent disturbance, resetting plantation succession and creating a more homogenous community.

From the visual assessment, changes in vegetation type on some sites would alternate between woody and broadleaf species, even within the same year. These variations could be attributed to the transition from herbaceous to woody dominance with increased leaf area. Another possible explanation could be when the assessment was conducted, spring versus later summer. Some species grow more rapidly in the spring and others late in the growing season. Control plots would have low vegetation levels during spring assessments and then high levels at the end of the growing season. Sites with high vegetation in the spring may be controlled, causing lower vegetation levels mid-summer. Then by late summer, the vegetation levels have returned to a higher level. Others have observed late summer herbaceous regrowth, even with vegetation control earlier in spring and summer (Miller et al. 2003a). Dogfennel, in the Asteraceae family, blooms in late summer or as late as fall.

The visual assessment provided a simple, repeatable method to determine the vegetation level and type in midrotation loblolly pine plantations across a Lower Coastal Plain landscape. From the visual assessment, forest managers are able to determine where additional vegetation control is necessary. When vegetation control is maintained, the treatment plots, UCV is suppressed. Less frequent control methods, the control plots, only temporarily suppress unwanted vegetation. Thinning resets plantation succession.

COMPETING VEGETATION BIOMASS

2. Estimating midrotation loblolly pine planation understory competing vegetation (UCV) biomass based on a visual assessment at Hofmann Forest, NC

2.1 Introduction

The understory vegetative community on young loblolly pine plantations changes as loblolly matures through midrotation. During the rotation establishment phase, loblolly pine trees are young with low leaf area, allowing ample sun to reach the forest floor. The presence of usable light, photosynthetically active radiation (PAR), and recent disturbances from site preparations, promotes the growth of pine and herbaceous (grass; grass-like; broadleaf; forbs) species. These species are pioneer, early successional species, mostly shade intolerant and respond well to disturbances. Light provides the energy necessary to drive photosynthesis and create plant biomass. As pines grow, they become dominant through height and diameter growth, expanding their crowns and increasing leaf area. Increases in leaf area, increases the amount of PAR intercepted by pine leaves. More light intercepted by pine means less light is reaching the forest floor. As shade takes over the forest floor, less tolerant grasses and broadleafs are shaded out. More shade tolerant species, such as young hardwoods, now have the opportunity to grow. These transitions occur in both natural and managed forests. Examples of these vegetative dynamics in managed pine plantations have been studied by others.

During the first growing season of a naturally regenerated clearcut loblolly stand, at a SC Piedmont site, biomass accretion was primarily in herbaceous plants; first year total biomass was 85 percent herbaceous and aboveground biomass, for two watersheds, equaled 3,131 and 2,456 kg ha^{-1} (Cox and Van Lear, 1984). Pine dominated by end of fifth growing season and the biomass accumulation favored pine and hardwoods over other herbaceous vegetation. Herbaceous vegetation peaks at three to four years after planting; loblolly becomes dominant by age seven (Schultz, 1997). Miller et al. (2003a) observed similar vegetative dynamics in 15 year old unthinned loblolly pine, across the SEUS, receiving nearly complete vegetation control treatments (woody; herbaceous; woody plus herbaceous) during the first three to five years of growth. Miller reported herbaceous plants colonized the understory initially but declined, on all treatments, around year eight when the canopy cover (pine and/or hardwood) reached 50 to 60 percent. Woody evergreen shrubs and unwanted trees are major competitors from before crown closure through midrotation (Oppenheimer et al. 1998; Miller et al. 2003a).

Crown closure, or canopy closure, occurs when little light penetrates the canopy. Another description is little to no sky is visible from a point on the ground, under a forested canopy. Loblolly pine crown closure varies with site quality and natural resource availability, but can occur as early as rotation age of seven to ten. Under dense canopy cover, the understory vegetative community continues to experience decreases in the amount of herbaceous vegetation and a corresponding increase in woody vegetation. In a ten year old stand, with a closed pine canopy, the number of understory herbaceous species was the same as a mature, well-stocked pine-hardwood stand (Stansky et al. 1986). The mature stand (45 years old) consisted of 14 and 86 percent of the total net community productivity in herbaceous and woody vegetation, respectively.

Measuring leaf area index (LAI) can provide insights into the capacity and performance of loblolly pine to capture and use the available natural resources in a stand. LAI can also be used to quantify understory competition. Pine leaf area affects the productivity of both pine and the understory competing vegetation (UCV). On flatwoods pine plantations in GA and FL, during midrotation (rotation age 7 to 10), high understory leaf area index (LAI) (2 m^2 m^{-2}) was observed and attributed to the absence of crown closure seen by low loblolly pine LAI (3 m^2 m^{-2}) (Peduzzi et al. 2010). The authors report low overstory pine leaf area corresponds with high understory LAI, negatively correlated (-0.694), indicating light might be the most important factor affecting understory survival and/or the ability for understory species to thrive in low nutrient environments (Peduzzi et al. 2010).

Vegetative communities could be considered strong competitors if they successfully acquire light, water and nutrition when in competition with other plants. Successful competition can be identified from not only their presence or how frequently they occur, but also how much biomass is there. Biomass indicates a plant has acquired enough resources to not only survive but to grow. In southern pine plantations, understory LAI, percent cover, species richness and arborescent and/or non-arborescent heights, stem counts and basal areas have previously been determined (Clason, 1993; Zutter and Miller, 1998; Miller et al. 2003; Peduzzi et al. 2010; Albaugh et al. 2012b). However, UCV community productivity, or aboveground biomass, is not well quantified. Quantifying the amount of aboveground biomass of the UCV communities provides insights to where and when unwanted vegetation is accessing the natural resources. Biomass is an indication to how well vegetation is surviving and growing because with unsuccessful capture of resources, there would be no accumulation of biomass.

2.2 Objectives

1. Quantify competing vegetation biomass in the understory of control plots at Hofmann Forest.
2. Express understory competing vegetation biomass as a function of overstory loblolly pine leaf area index (LAI).
3. Compare loblolly pine LAI in treatment versus control plots.

2.3 Methods and Materials

Competing vegetation was harvested from the control plots, within each of the 40 twin plots at Hofmann Forest, NC during the end of the 2013 growing season (September). A thorough investigation of the understory competing vegetation (UCV) conditions was conducted first by walking the boundary of the plot and then throughout the plot. Transects were walked up and down each row, across rows and diagonally to observe the understory vegetation from all directions. The height of the vegetation, the percent coverage and the relative abundance of each species was considered to establish the average conditions. A sample area was chosen most representative of the average plot conditions, including the dominant and co-dominant species. The sample area would begin and end along the beds of planted pine to capture the vegetation under loblolly pines and in between the rows. A half meter by six meter (0.5 by 6.0 m) belt transect was measured to create a three square meter (3 m^2) sample area (Figure 9). The transect length was oriented from one row to the next, either perpendicularly or diagonally, to include the variation in vegetation within the plot. A belt transect was chosen to harvest the woody and herbaceous vegetation based on the *Standard methods for forest herbicide research*, by the Southern Weed Science Society (Miller and Glover, 1991). Instead of sampling excessively large areas within the measurement plot (Figure 4), a single belt transect was used, conserving time and resources. Measuring tapes were used to create the sample area (Figure 9). Metal stakes with a loop were used to mark the four corners of the sample area; each stake had bright flagging for visibility (Figure 9).

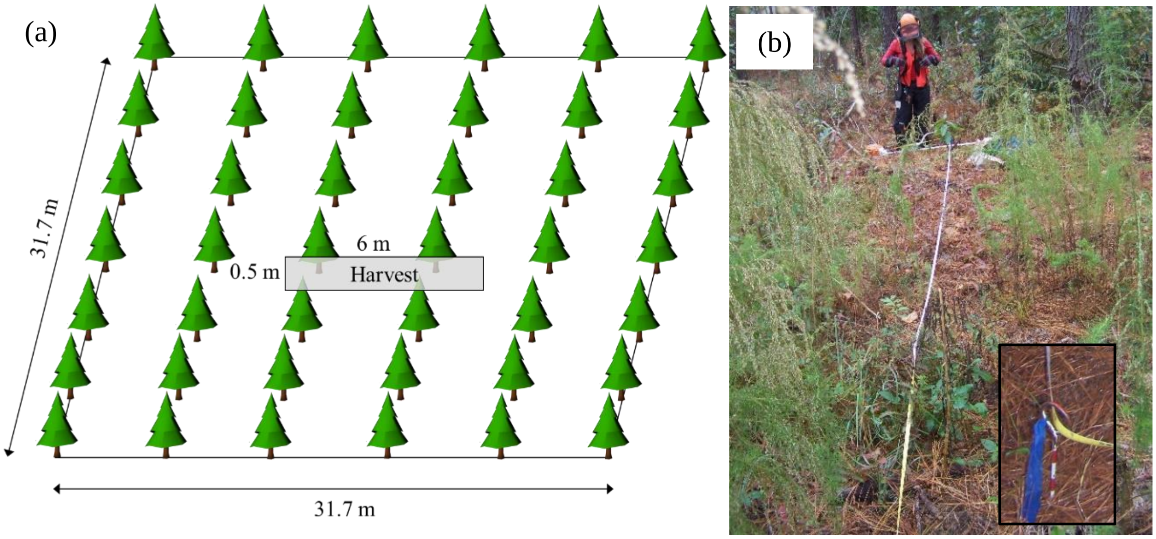


Figure 9: Schematic of the competing vegetation biomass area harvested (a) within the control plots at Hofmann Forest, NC in September 2013. Photograph (b) shows the measurement of the sample area in the field. The insert image shows the metal stake used to mark the four corners.

Using a Stihl brush cutter with a chainsaw blade, all UCV was harvested at ground level, within the predetermined sample area (Figure 10). Only plants rooted within the sample area were harvested. The safety guard on the brush cutter prevented a complete harvest of the stumps; ten centimeter stumps were left intact. A subsample of six control plots had the remaining stumps clipped, cut and sawed flush with the surface of the ground. A regression analysis was used to extrapolate the remaining stump biomass for each control plot. All cut living material was put into large plastic bags, removing any dead debris. Entire bag(s) were weighed using an Adam Equipment CPWplus 6 bench scale, six kilogram capacity and two gram readability (Figure 10). The green weight was recorded for the entire harvested sample in the field. The weight of the plastic bag was subtracted during calculations. Next, the vegetation was removed from the bags, cut into smaller pieces (0.3 meters or less) and mixed thoroughly in a large container to homogenize the vegetation. From the well mixed pile, a random composite sub-sample was gathered, re-weighed and returned to the lab for further analysis. The target weight for the sub-sample was one kilogram. Each bag was labeled according to the twin plot and kept cool.

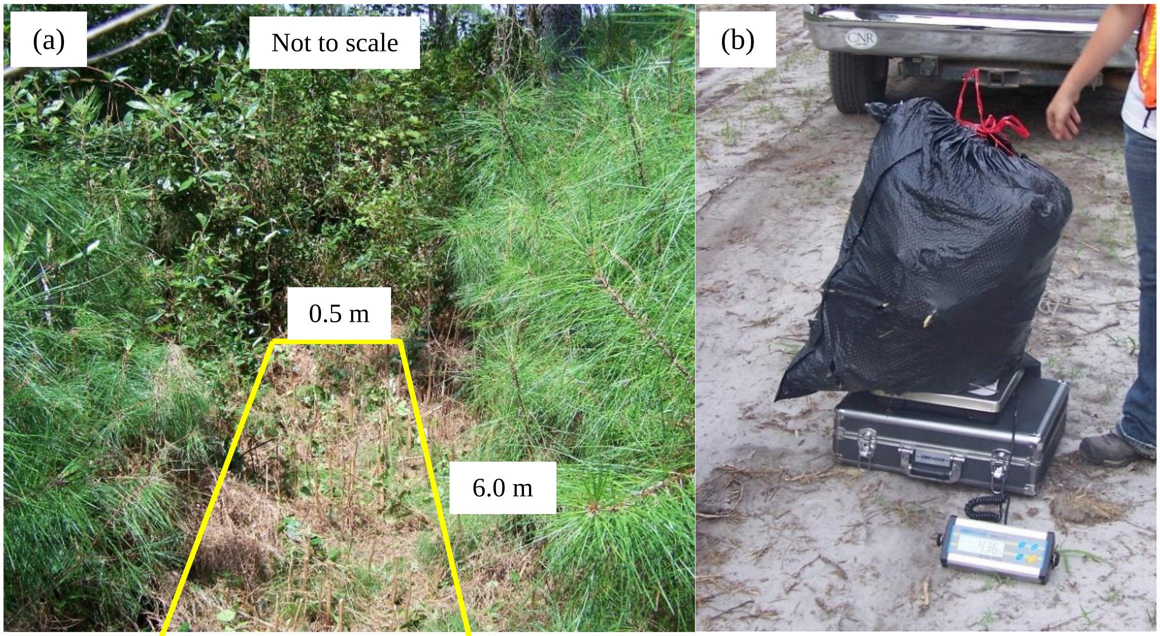


Figure 10: Sample area for competing vegetation harvest (a) in the field. Weighing the vegetation in the field (b); measuring green weight of sample. Biomass harvest and weight took place at Hofmann Forest, NC in September 2013.

Upon returning to the NCSU lab, all composite subsamples were sorted by growth form: woody or perennial tissue (stems; bark; twigs) and canopy or ephemeral tissue (leaves; green stems). Vegetative material was separated because the physiological processes involved in woody versus canopy tissue development vary. Therefore, the nutritional status is also different. Sorted subsamples were transferred to paper bags and oven dried at 65 to 70°C until constant weight. The final dry weight was measured using the same Adam equipment scale. From the moisture content in the woody and canopy components, the total UCV biomass was expanded to a megagram per hectare (Mg ha^{-1}). The moisture content was determined from the proportion of the net subsample biomass dry weight to green weight, multiplied by the control plot net green weight. The moisture content was then divided by the sample area (3 m^2) and converted to megagram per hectare (Mg ha^{-1}).

In February 2014, overstory loblolly pine leaf area index (LAI) was measured using a LiCor LAI-2200 Plant Canopy Analyzer, with a 90° view cap, under diffuse sky, during dawn and dusk. Measurements were taken in both the control and treatment plots. Above and below canopy wands were synced at each twin plot location and had identical view caps. The above canopy sensor was set up adjacent to each twin plot location in harvested areas, or along roadsides, and was used for both the control and treatment readings (Figure 11). Within the plots, 30 below canopy measurements were taken along a transect perpendicular to the edge of the planted rows, opposite from the sun. Sensors were oriented the same direction, in relation to the sun, to view the same sky. The below canopy wand was held upward, level and above the understory vegetation to prevent interference (Figure 11). No measurements were taken under competing hardwood canopies. The above and below canopy measurements were merged and LAI was computed using LiCor, Inc. FV-2200 software.

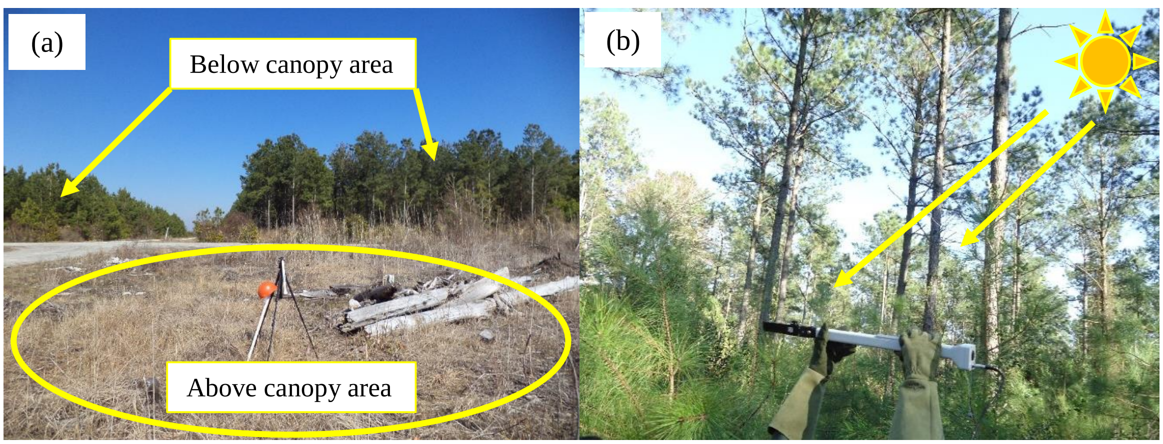


Figure 11: Leaf area index (LAI) was measured at Hofmann Forest, NC in February 2014. Example set up of an above canopy sensor wand in a clearing (yellow circle) at least 3.5 times the height of the nearby canopy (yellow arrows) but as close as possible to the twin plot (a). Below canopy sensors were held above the understory vegetation to prevent interference and only capture the overstory loblolly pine LAI (b). Below canopy measurements were made parallel to the last planted row, opposite from the sun's location.

2.4 Results

2.4.1 Understory Competing Vegetation (UCV) Biomass

The net green weight of UCV harvested from the control plots ranged from 0.4 to 16.8 kilograms, with a mean value of 4.2 kilograms, for a total of 165.4 kilograms. Net refers to the weight of only the competing vegetation, excluding any bags used to weigh the material. The correlation between net green weight and biomass is found in Figure 12. Green weight was positively correlated to the biomass with a correlation coefficient of 0.94. The control plot from twin plot three, with no living vegetation, was omitted from the biomass analysis because of the additional aerial herbicide treatment it received prior to the assessments. This additional vegetation control corresponds more to the treatment plots than the controls plots. Therefore, the lack of vegetation is considered a mishap and not indicative of the actual treatment. Twin plot three will be omitted in the biomass analysis hereinafter.

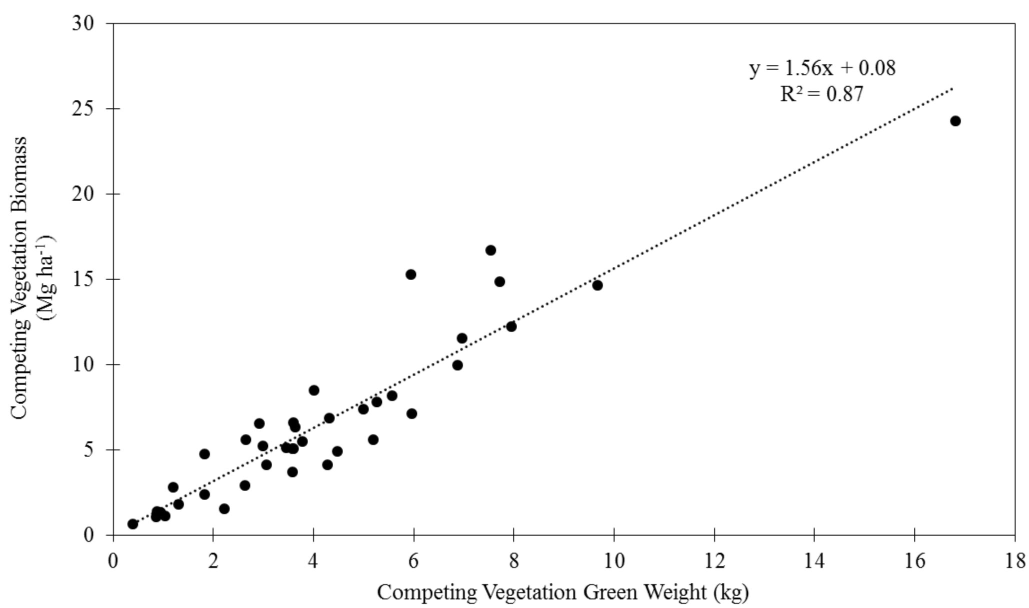


Figure 12: Understory competing vegetation net green weight, in kilograms, over the three square meter sample area as a function of the dried biomass, in megagrams per hectare. The net green weight is without the storage bags. Green weight was positively correlated to biomass; correlation coefficient was 0.94. Vegetation was harvested at Hofmann Forest, NC in September 2013.

The level and type UCV varied across the 40 control plots. Differing vegetation types and levels led to a range of total aboveground biomass (Figure 13). The total biomass includes the canopy (solid green) in addition to the woody components (yellow stripes). Canopy refers to foliage or ephemeral tissue. Woody refers to bark, stems and other woody material or perennial tissue. As mentioned earlier, twin plot three with no biomass, was not included in the mean or range values, but is shown in Figure 13. Thinning affected the amount of biomass present in the control plots (Figure 13). For the 23 unthinned twin plots, the canopy component of biomass ranged from 0.6 to 11.6 megagrams per hectare and had a mean of 5.0 megagrams per hectare. The woody component ranged from 0 to 5.1 megagrams per hectare with a mean of 1.3 megagrams per hectare. Total competing vegetation biomass ranged from 0.7 to 16.7 megagrams per hectare with a mean of 6.3 megagrams per hectare. There were 17 thinned twin plots. Canopy biomass ranged from 1.3 to 23.2 megagrams per hectare with a mean of 6.1 megagrams per hectare. The woody biomass component ranged from 0 to 8.3 megagrams per hectare with a mean of 1.1 megagrams per hectare. Total biomass in the thinned control plots ranged from 1.4 to 24.3 megagrams per hectare and had a mean of 7.2 megagrams per hectare.

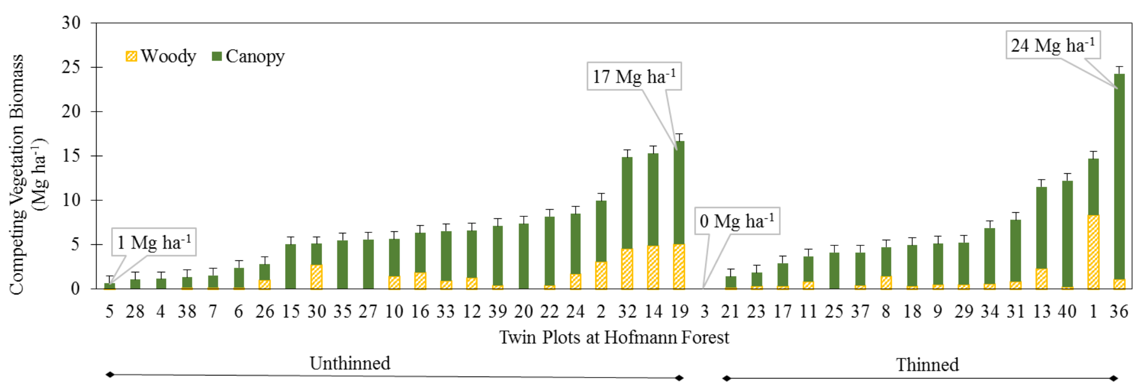


Figure 13: Aboveground competing vegetation biomass in the control plots, having not been thinned (left) and having been thinned (right). The woody component (bark and stems) of the biomass is shown as the yellow striped portion of the bars and the canopy component (foliage) as the solid green portion. Twin Plot three had no competing vegetation. Error bars are the standard error (0.81) of the total biomass, for all twin plots. Biomass harvests from Hofmann Forest, NC in 09-2013.

2.4.2 UCV Biomass and Visual Assessment

A comparison of the distribution of total biomass by each UCV level, from the visual assessment, can be found in Figure 14. Here biomass refers to the combination of canopy and woody components, or total biomass. For no competing vegetation cover (none), there was no biomass. Twin plot three was the only control plot designated as none. There were five low level control plots. Biomass in the low UCV levels ranged from 0.7 to 2.9 megagrams per hectare, with an average biomass of 1.8 megagrams per hectare. Medium level biomass ranged from 1.1 to 7.4 megagrams per hectare. There were nine medium control plots and the average biomass was 3.4 megagrams per hectare.

With 25 high level control plots, the range of biomass was 4.1 to 24.3 megagrams per hectare. In the interest to understand the large biomass variability in high vegetation levels, high level control plots were divided into subcategories based on the vegetation type (Figure 14). Six control plots had broadleaf vegetation at high levels with total biomass ranging from 4.1 to 7.1 megagrams per hectare, with an average of 5.3 megagrams per hectare. There was only one high level control plot with grass vegetation, biomass totaling 12.2 megagrams per hectare. The largest group of high level control plots was woody dominated. There were 18 high woody control plots, biomass ranging from 4.7 to 24.3 megagrams per hectare, with an average of 9.8 megagrams per hectare. There are no outliers in the high level woody control plots even though the distribution is large.

The sums of low, medium and high levels of UCV total biomass were 8.9, 31.0 and 220.9 megagrams per hectare, respectively. The three levels combined made up a total of 260.8 megagrams per hectare of UCV biomass in the control plots at Hofmann Forest. Control plots with low level UCV consisted of 3.4 percent, medium level 11.9 percent and high level contained 84.7 percent of the total biomass harvested. The none level plot had zero percent biomass.

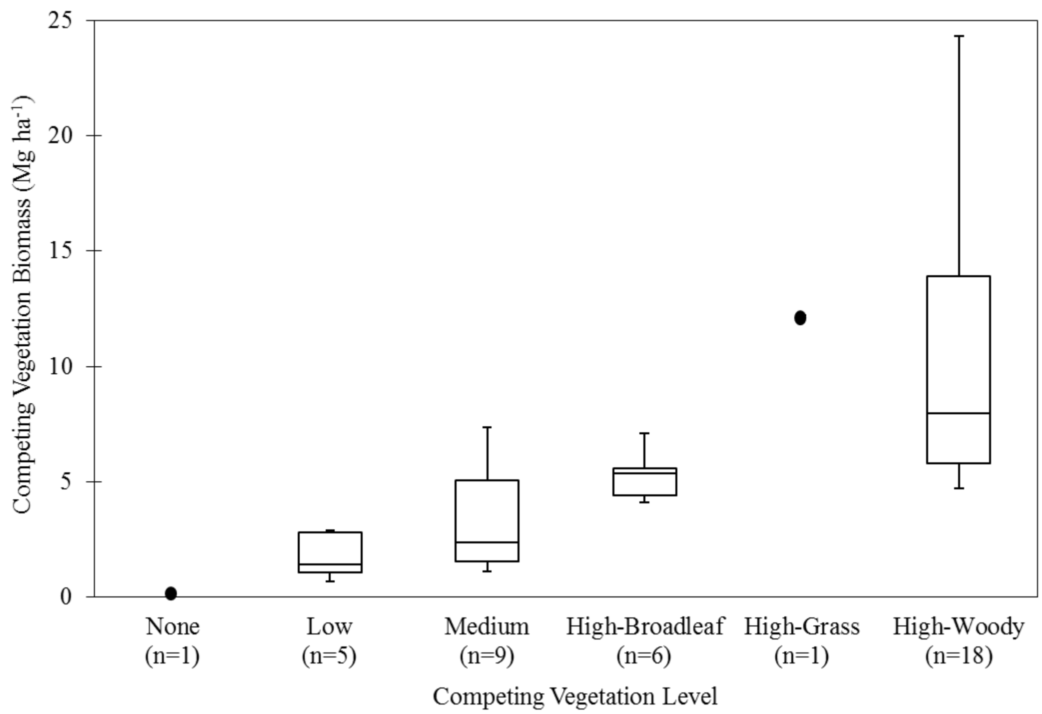
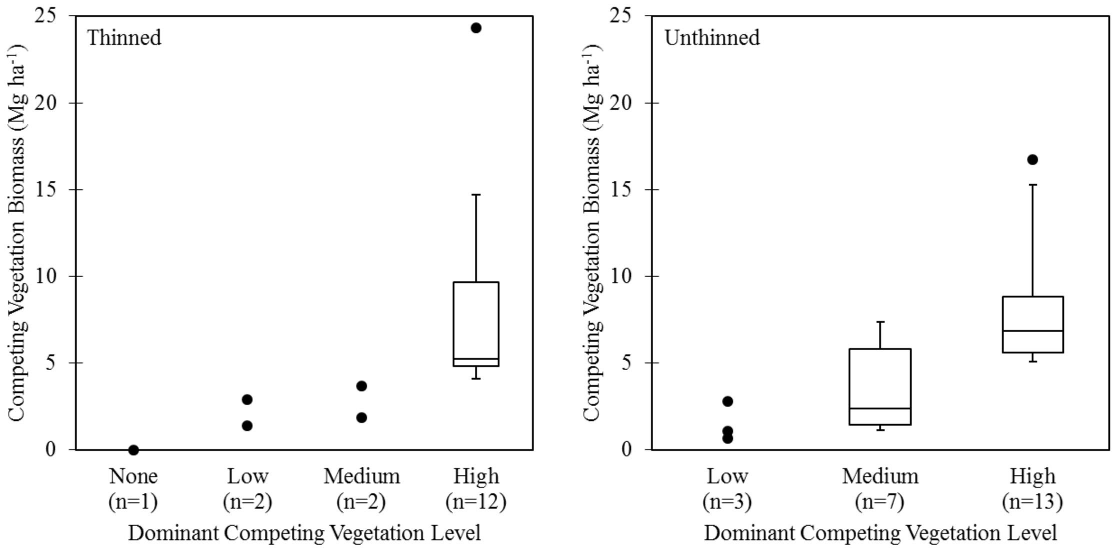


Figure 14: Understory competing vegetation biomass (Mg ha^{-1}) by the competition level. High competition levels are further divided by the vegetation type. Biomass was harvested at Hofmann Forest, NC in September 2013. In parenthesis, n refers to the number of control plots.

Comparing the distribution of the total UCV biomass by the visual assessment level in thinned versus unthinned stands is worthwhile to consider (Figure 15a). There were two low level thinned control plots with total biomass of 1.4 and 2.9 megagrams per hectare compared to three low unthinned control plots with 0.7, 2.8 and 1.1 megagrams per hectare. Thinned stands had two medium control plots with corresponding biomass of 1.8 and 3.7 megagrams per hectare. The seven unthinned medium control plots ranged from 1.1 to 7.4 megagrams per hectare and averaged 3.6 megagrams per hectare. Thinned stands had 12 high while unthinned stands had 13 high level control plots. The range of biomass in thinned versus unthinned high level control plots was 4.1 to 14.7 versus 5.1 to 15.3 megagrams per hectare. High level outliers were 24.3 and 16.7 megagrams per hectare, thinned and unthinned. The averages were 8.8 and 8.9 megagrams per hectare biomass in thinned and unthinned control plots, respectively.

(a) Level



(b) Type

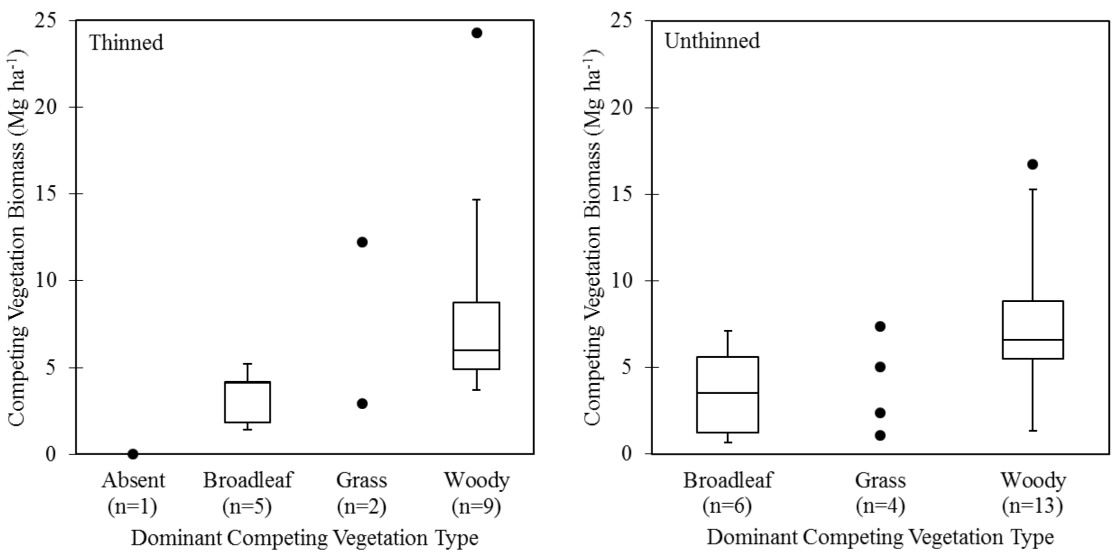


Figure 15: Distribution of competing vegetation biomass (Mg ha^{-1}) by the competition level (a) and dominant vegetation type (b), in thinned versus unthinned control plots. Measurements from Hofmann Forest, NC September 2013. In parenthesis, n refers to the number of control plots.

The UCV biomass for each dominant vegetation type, from the visual assessment, broadleaf, grass and woody, was determined. The distribution of harvested biomass by the type can be found in Figure 15b, as a comparison between thinned and unthinned stands. Only thinned stands had a control plot absent of vegetation. Thinned twin plots had five broadleaf, two grass and nine woody dominant vegetation types. For the thinned stands, broadleaf biomass ranged from 1.4 to 5.2 megagrams per hectare, grass biomass was 2.9 and 12.2 megagrams per hectare and woody biomass ranged from 3.7 to 14.7 with one outlier of 24.3 megagrams per hectare. The mean UCV biomass in thinned stands for broadleaf, grass and woody species was 3.3, 7.6 and 9.3 megagrams per hectare, respectively. Summation of broadleaf, grass and woody biomass equaled 16.7, 15.1 and 83.7 megagrams per hectare for a combined total of 115.5 megagrams per hectare. Broadleaf biomass made up 14.5 percent, grass consisted of 13.1 percent and woody 72.4 percent of the total biomass harvested in thinned twin plots.

Compared to thinned, unthinned twin plots had six broadleaf, four grass and 13 woody dominant vegetation types for the control plots (Figure 15). UCV broadleaf biomass ranged from 0.7 to 7.1 megagrams per hectare, grass biomass from 1.1 to 7.4 megagrams per hectare and woody biomass from 1.3 to 15.3 megagrams per hectare. The woody vegetation type had one outlier in the distribution of 16.7 megagrams per hectare. The average biomass for the vegetation types, broadleaf, grass and woody, in unthinned control plots were found to be 3.6, 4.0 and 8.3 megagrams per hectare, respectively. Total broadleaf biomass was 21.6 megagrams per hectare, total grass was 15.9 megagrams per hectare and total woody was 107.8 megagrams per hectare. Total UCV biomass in all unthinned control plots equaled 145.2 megagrams per hectare. Broadleaf biomass made up 14.9 percent, grass 10.9 percent and woody 74.2 percent of the total biomass harvested in thinned twin plots.

From the distributions of UCV biomass, there are observed differences in how much competing vegetation biomass is present based on the level and vegetation type. To determine associations between level and type of UCV biomass, the relative frequencies were calculated (Table 16). The total amount of biomass for each combination is provided, first row of each level. The percent frequency, second row in italics, was calculated by the ratio of the group biomass to the total biomass harvested from all control plots (260.8 Mg ha^{-1}). Twin plot three, with no vegetation, was omitted from this analysis. Similar to the relative frequency analysis for the counts of control plots from the visual code, the strongest association was high and woody control plots at 68 percent. The other main association was between high and broadleaf control plots at 12 percent. A weak association exists for the medium grass combination (6%) and the high grass group (5%). Little to no association exists between the other types and levels, because the relative frequencies are not different from at least one other combination. The interaction between the level and type of competing vegetation biomass could not be tested using Chi Square Test, because more than one of the expected frequencies was less than five. Therefore, an appropriate test of significance could not be conducted.

Table 16: Harvested biomass association between the level and type of dominant vegetation. First, the biomass summation for each group is provided. Percentages are the relative frequencies of the level and type biomass compared to the total biomass from all control plots (260.8 Mg ha^{-1}). The twin plot with no vegetation was omitted from analysis. Levels, dominant vegetation type and biomass were determined in September 2013 at Hofmann Forest, NC.

Competition Level	**Biomass of Dominant Type (Mg ha^{-1})**			
	Broadleaf	**Grass**	**Woody**	**Totals**
High	31.7	12.2	177.0	**220.9**
	12%	*5%*	*68%*	*85%*
Medium	4.5	14.8	11.6	**31.0**
	2%	*6%*	*4%*	*12%*
Low	2.1	4.0	2.8	**8.8**
	1%	*2%*	*1%*	*3%*
Totals	**38.3**	**31.0**	**191.5**	**260.8**
	15%	*12%*	*73%*	*100%*

Regression lines were fitted to the dominant competing vegetation type, identified from the visual assessment (woody; broadleaf; grass), in relation to the competition level (x-axis) and the amount of biomass harvested (y-axis) (Figure 16). The values of x were set to one for none, two for low, three for medium and four for high to capture the change in biomass with level increase. Vegetation levels and x values are both ordinal. Exponential regressions were the best fits for broadleaf and woody vegetation types. Linear regression produced the highest R-squared value (0.75) for grass vegetation, but the y-intercept was a negative value, not physically possible in the environment. Therefore, an exponential regression was applied to grass vegetation. Regressions were used for each vegetation type separately, because this division improved the coefficient of determination (R-squared) from 0.28, for all competing vegetation types, to 0.36, 0.85 and 0.69 for woody, broadleaf and grass vegetation, individually. The R-squared for only the competition level was 0.56. Any potential outliers were included, but the twin plot with no vegetation was not.

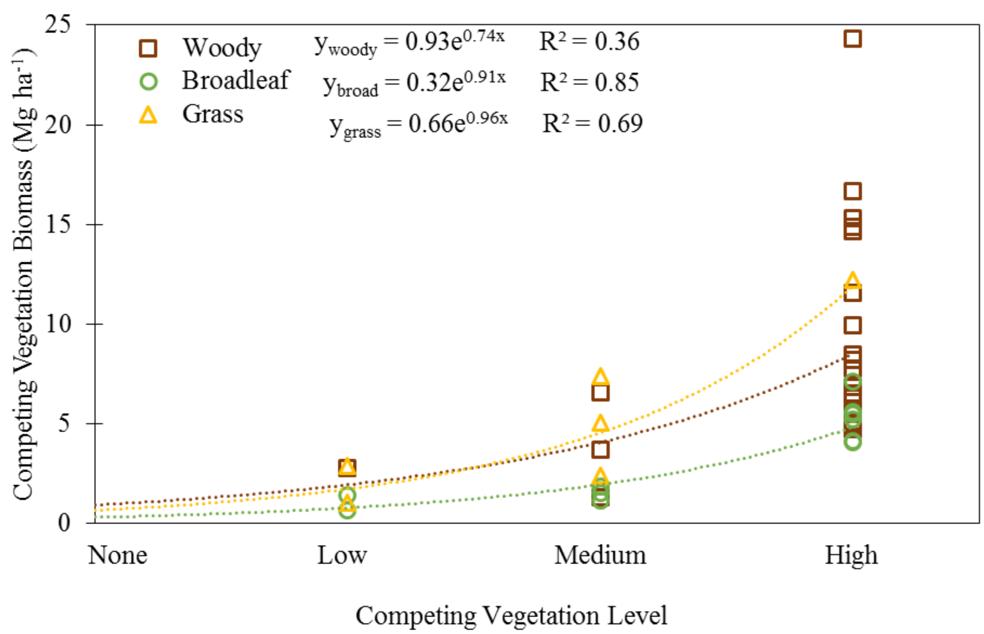


Figure 16: Competing vegetation level as a function of biomass. The vegetation type is included, shown by the brown squares (woody), green circles (broadleaf) and yellow triangles (grass). For each vegetation type, an exponential regression was applied. The corresponding equations and the R-squared values for each type are shown. Observations were conducted in September 2013 at Hofmann Forest.

2.4.3 UCV Biomass on Mineral and Organic Soils

The bulk of the UCV biomass on thinned twin plots occurred on high woody control plots with mineral soil and consisted of 29 percent of the total biomass harvested (Table 17). On unthinned twin plots, high woody control plots with organic soil had the most biomass at 26 percent of the total biomass. There were greater values of broadleaf biomass in unthinned control plots for both soil types. In thinned stands, grass biomass was greater in mineral soil compared to unthinned stands where grass biomass was greater in organic soil. A similar response was observed with woody dominant vegetation. Thinned control plots had a greater amount of woody UCV biomass in mineral soils. Unthinned control plots had higher amounts of woody UCV biomass in organic soils. Overall, mineral soils had a total of 136.0 megagrams per hectare of biomass and organic soils had 124.8 megagrams per hectare. In both soil types, UCV biomass increased as the competition level increased. Organic soils had more UCV biomass in the low and medium vegetation levels. In the high vegetation level, there was more biomass in mineral than organic soils.

Table 17: Competing vegetation biomass, in thinned against unthinned control plots, by dominant vegetation type for each vegetation level in either organic or mineral soil. Column and row totals are by mineral and organic soils, with the grand totals in the bottom right. One control plot, in mineral soil, was omitted because it had no living vegetation. Analysis was conducted at Hofmann Forest, NC in September 2013.

		Competing Vegetation Level							
		Low		**Medium**		**High**		**Totals**	
		Mineral	**Organic**	**Mineral**	**Organic**	**Mineral**	**Organic**	**Mineral**	**Organic**
Thinned	**Broadleaf**	---	1.4	1.8	---	5.2	8.2	**7.1**	**9.6**
	Grass	---	2.9	---	---	12.2	---	**12.2**	**2.9**
	Woody	---	---	---	3.7	75.0	4.9	**75.0**	**8.6**
Unthinned	**Broadleaf**	0.7	---	2.7	---	5.5	12.7	**8.9**	**12.7**
	Grass	---	1.1	2.4	12	---	---	**2.4**	**13.5**
	Woody	---	2.8	---	8	30.4	66.7	**30.4**	**77.4**
	Totals	**0.7**	**8.2**	**6.9**	**24.1**	**128.4**	**92.5**	**136.0**	**124.8**

The relationship between soil quality and UCV was assessed (Figure 17). To fully investigate potential relationships, the data was separated by the dominant vegetation type. The UCV biomass is not correlated to the percent of carbon (organic matter) in the top 40 centimeters of the soil. The correlation coefficient of percent carbon and UCV biomass was 0.04, so there is no relationship. Correlations of soil and UCV biomass by dominant vegetation type were as follows: broadleaf vegetation was weakly positive (0.31); grass vegetation was weakly negative (-0.26); woody vegetation had no correlation (-0.01). Correlations of soil and UCV biomass by vegetation level were better for low and medium levels, but there was no correlation at the high level; low level was moderately positively correlated (0.60); medium level was somewhat positive (0.44); high level had no correlation (0.04).

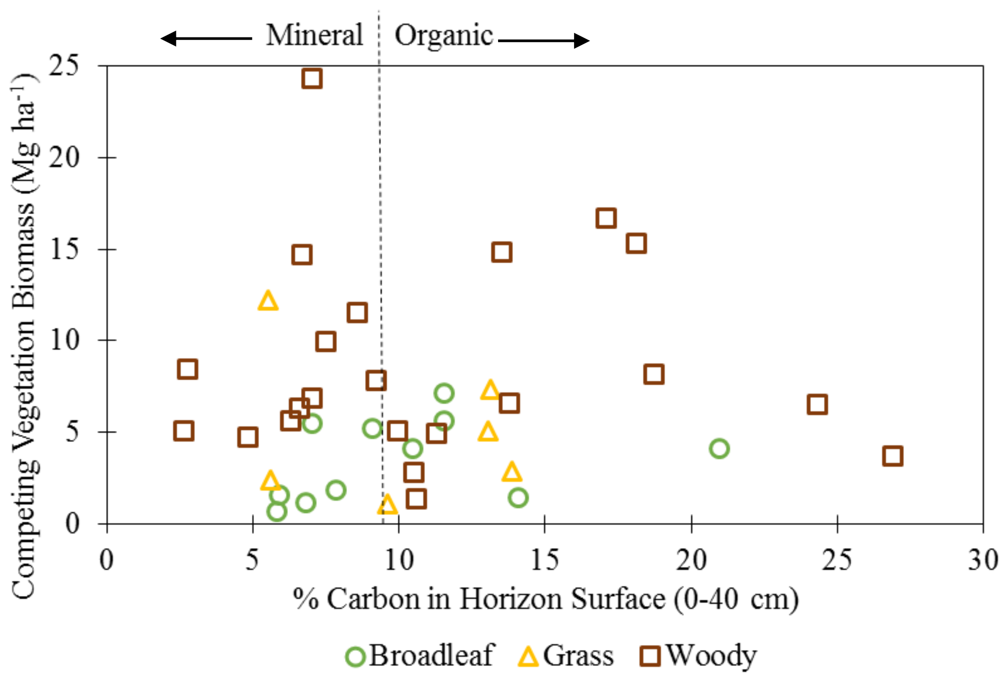


Figure 17: Competing vegetation biomass (Mg ha^{-1}) as a function of the percent of carbon (organic matter; 0-40 cm). Soils, mineral (left) versus organic (right), are divided by the vertical line at 9.42 percent carbon. Organic soils are Histosols. Mineral soils are Spodosols, Ultisols and one Inceptisol. The dominant vegetation type can be identified by the shape and color of each point. Broadleaf vegetation are shown as green circles, grass as yellow triangles and woody vegetation as brown squares. Biomass was harvested in September 2013 and soil analysis was completed in 2013, at Hofmann Forest.

2.4.4 UCV Biomass and Species Characterization

The dominant and co-dominant species biomass was measured collectively, by control plot. Therefore, individual species biomass cannot be determined. The LAI and combined biomass, dominant and co-dominant species can be found in Table 18.

Table 18: Hofmann Forest control plot competing vegetation biomass and pine leaf area index for dominant species, in thinned and unthinned stands, ranked by the greatest biomass.

Thinning Date	Age (2013)	Soil Taxonomy (Order)	Level*	Control Dominant Species	Control Co-Dominant Species	Comp.Veg. Biomass (Mg ha^{-1})	Pine Leaf Area Index (m^2 m^{-2})
2007	23	Spodosol	H	*Pinus taeda*	*Ilex coriacea*	24.3	1.1
2005	21	Ultisol	H	*Pinus taeda*	*Acer rubrum*	14.7	1.6
2008	23	Spodosol	H	*Andropogon virginicus*	*Acer rubrum*	12.2	1.0
2004	21	Ultisol	H	*Pinus taeda*	*Ilex coriacea*	11.6	0.7
2004	24	Spodosol	H	*Persea palustris*	*Acer rubrum*	7.8	1.0
2008	19	Spodosol	H	*Cyrilla racemiflora*	*Smilax glauca*	6.9	1.3
2012	10	Inceptsol	H	*Eupatorium capillifolium*	*Dichanthelium commutatum*	5.2	1.7
2003	21	Ultisol	H	*Acer rubrum*	*Arundinaria gigantea*	5.1	0.9
2006	19	Histosol	H	*Pinus taeda*	*Eupatorium capillifolium*	4.9	0.7
2003	21	Ultisol	H	*Acer rubrum*	*Pterifium aquilinum*	4.7	1.0
2007	23	Histosol	H	*Eupatorium capillifolium*	*Andropogon virginicus*	4.1	1.3
2012	12	Histosol	H	*Eupatorium capillifolium*	*Dichanthelium commutatum*	4.1	1.9
2010	15	Histosol	M	*Rubus sp.*	*Aralia spinosa*	3.7	1.2
2013	14	Histosol	L	*Dichanthelium commutatum*	*Pteridium aquilinum*	2.9	1.5
2012	14	Spodosol	M	*Eupatorium capillifolium*	*Andropogon virginicus*	1.8	1.4
2013	10	Histosol	L	*Smilax glauca*	*Rubus sp.*	1.4	1.3
2006	18	Spodosol	N	Absent	Absent	0.0	1.0
	14	Histosol	H	*Persea palustri*	*Lyonia lucida*	16.7	0.8
	9	Histosol	H	*Ilex coriacea*	*Acer rubrum*	15.3	1.6
	13	Histosol	H	*Lyonia lucida*	*Acer rubrum*	14.9	1.4
	4	Ultisol	H	*Rubus sp.*	*Lyonia lucida*	10.0	2.0
	7	Spodosol	H	*Ilex coriacea*	*Aralia spinosa*	8.5	1.9
	4	Histosol	H	*Ilex coriacea*	*Solidago sp.*	8.2	1.4
	9	Histosol	M	*Carex glaucescens*	*Erechtites hieraciifolius*	7.4	2.4
	12	Histosol	H	*Eupatorium capillifolium*	*Dichanthelium commutatum*	7.1	1.7
	7	Histosol	M	*Ilex coriacea*	*Cyrilla racemiflora*	6.6	1.7
	4	Histosol	H	*Ilex coriacea*	*Smilax laurifolia*	6.5	1.1
	6	Ultisol	H	*Ilex coriacea*	*Persea palustris*	6.3	2.4
	7	Ultisol	H	*Aralia spinosa*	*Ilex opaca*	5.6	1.7
	12	Histosol	H	*Eupatorium capillifolium*	*Dichanthelium commutatum*	5.6	1.8
	4	Spodosol	H	*Smilax laurifolia*	*Smilax glauca*	5.5	2.2
	5	Histosol	H	*Gordonia lasianthus*	*Cyrilla racemiflora*	5.1	2.4
	5	Histosol	M	*Carex glaucescens*	*Erechtites hieraciifolius*	5.1	1.8
	6	Histosol	L	*Rubus sp.*	*Gelsemium sempervirens*	2.8	2.6
	16	Ultisol	M	*Arundinaria gigantea*	*Pinus taeda*	2.4	1.8
	16	Ultisol	M	*Pteridium aquilinum*	*Acer rubrum*	1.6	2.4
	6	Histosol	M	*Rubus sp.*	*Smilax glauca*	1.3	2.9
	5	Ultisol	M	*Eupatorium capillifolium*	*Rubus sp.*	1.1	1.9
	7	Histosol	L	*Dichanthelium commutatum*	*Vitis rotundifolia*	1.1	3.0
	10	Ultisol	L	*Pteridium aquilinum*	*Toxicodendron radicans*	0.7	3.3

* H = high; M = medium; L = low; N = none.

2.4.5 UCV Biomass and Pine Leaf Area Index (LAI)

Loblolly pine LAI was measured in all twin plots during the dormant season (February 2014) after the visual assessment and biomass harvest. Loblolly pine LAI for the control plots, in thinned and unthinned twin plots, was comparable to the treatment plots (Figure 18). Pine LAI is divided by the dominant vegetation type (a; b; c), vegetation level (squares are low; triangles are medium, circles are high) and thinning (filled shapes are thinned; unfilled are unthinned). A one to one line (1:1) was drawn for easy comparison of LAI values of the control versus the treatment plots. Points above the line have higher LAI values in the treatment compared to the control plots. Points below the line have higher LAI values in the control related to the treatment plots. The unit for LAI is meters squared of leaves per meters squared of ground, but is typically reported as unit-less. From this point on, LAI will be written without units, under the previous understanding.

Loblolly pine LAI in the broadleaf dominated control plots (Figure 18a) ranged from 1.3 to 3.3, in contrast with the treatment plots, ranging from 0.6 to 3.1. However, the mean pine LAI in broadleaf control and treatment plots was the same, 1.9. In grass dominated control plots (Figure 18b), pine LAI averaged 1.9. The grass control plots had pine LAI values from 1.0 to 3.0 compared to the treatment plots range from 1.2 to 2.8. Loblolly pine LAI in the woody control plots (Figure 18c) ranged from 0.7 to 2.9 with an average of 1.5. The paired treatment plot ranged from 0.6 to 3.0 for pine LAI and had a mean of 1.4. One twin plot had no competing vegetation and the loblolly pine LAI was 1.00 and 0.83 in the control and treatment plots, respectively. This twin plot is not shown in Figure 18. The mean pine LAI in the low level control and treatment plots was 2.3. Loblolly LAI in low level control plots ranged from 1.3 to 3.3 and from 1.3 to 3.1 in the low treatment plots. Medium level control plot pine LAI ranged from 1.2 to 2.9 with an average LAI of 1.9. Medium level treatment plot pine LAI ranged from 0.9 to 2.7 with an average of 2.0. The minimum, maximum and mean loblolly LAI values for control compared to treatment plots was 0.7, 2.4 and 1.5 compared to 0.6, 2.2 and 1.3.

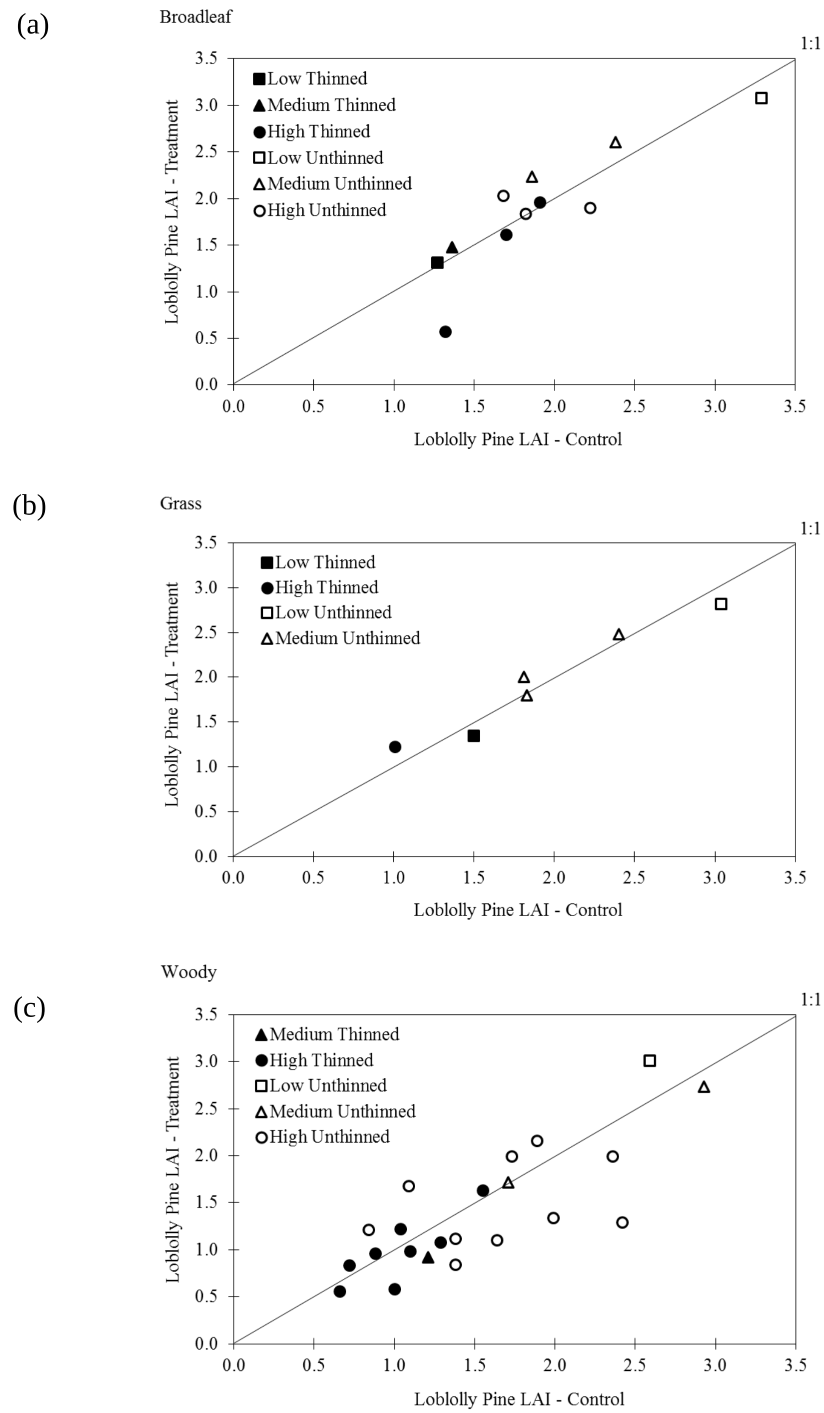


Figure 18: Loblolly pine leaf area index (LAI), by broadleaf (a), grass (b) and woody (c) vegetation in control versus treatment plots at Hofmann Forest, NC. A one to one (1:1) line was drawn for comparison of LAI values. Measurements were made in February 2014.

Loblolly pine LAI was plotted against the UCV biomass to investigate potential relationships between pine leaf area and the understory growth (Figure 19). Broadleafs are green shapes, grasses are yellow shapes and woody plants are brown shapes. Low vegetation levels are squares, medium levels are triangles and high vegetation levels are circles. Thinned twin plots are filled and unthinned are empty. Combining all of these characteristics shows how overstory pine LAI affects the competing vegetation biomass for each type and level. Differences due to thinning can also be observed.

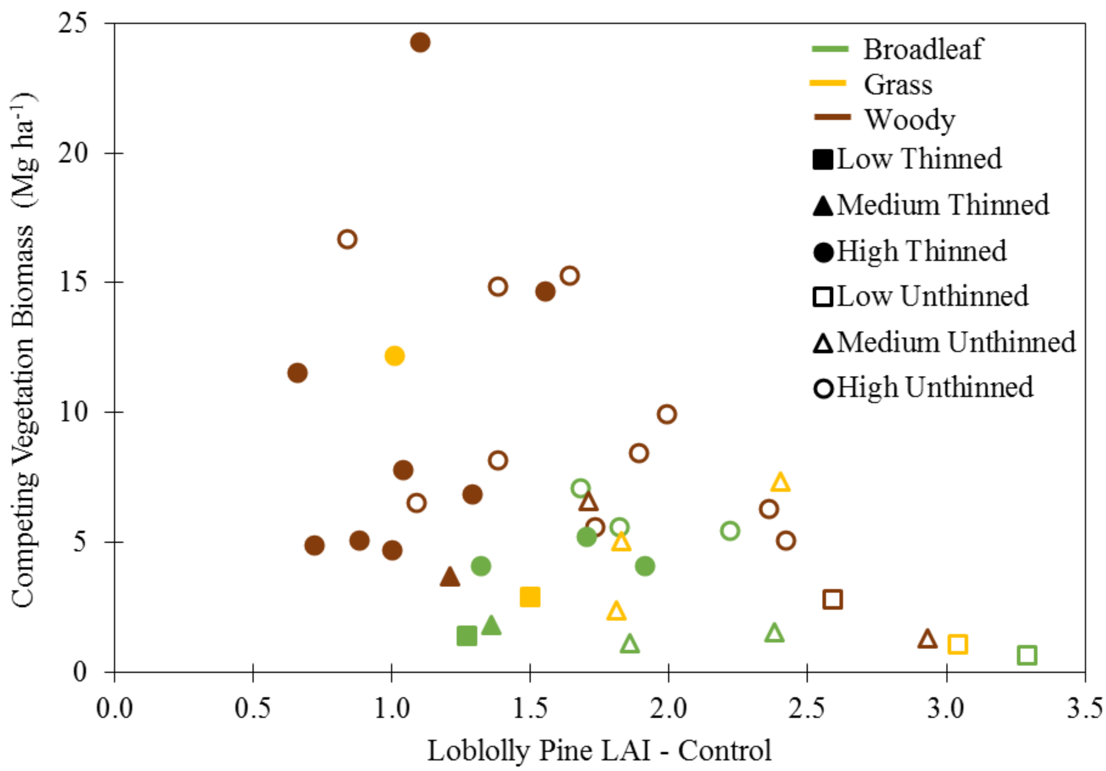


Figure 19: Aboveground competing vegetation biomass (Mg ha^{-1}) as a function of loblolly pine leaf area index (LAI) in the control plots at Hofmann Forest, NC. Filled shapes are thinned stands and unfilled are unthinned. Low vegetation levels are squares, medium levels are triangles and high vegetation levels are circles. Broadleaf dominant vegetation types are green, grass dominant types are yellow and woody dominant vegetation is brown. LAI was measured in February 2014 and biomass in September 2013.

2.5 Conclusion

The visual assessment was verified by the biomass harvest, providing agreeable predictions of understory competing vegetation (UCV) biomass. The biomass ranged from 0 to 24 megagrams per hectare in thinned stands and 1 to 17 megagrams per hectare in unthinned stands. Increases in the visual assessment level from low to high was supported by increasing UCV biomass. Of the total UCV biomass harvested, 68 percent of the biomass was on high-woody (HW) and 12 percent in high-broadleaf (HB) control plots. The biomass was highest in the high competing vegetation levels and lowest in the low vegetation levels. In the five control plots with the highest measured aboveground biomass, volunteer *Pinus taeda* (loblolly pine) and *Acer rubrum* (red maple) were the primary dominant and/or co-dominant species. *Ilex coriacea* (large gallberry), *Persea palustris* (swamp bay) and *Arundinaria gigantea* (giant cane) also contributed to high biomass levels.

There was a clear distinction for biomass between the medium and low vegetation levels compared to the high level. When the understory biomass was greater than five megagrams per hectare, high vegetation levels were found. When the understory biomass was less than five megagrams per hectare, none, low or medium vegetation levels were found. The distinction between low and medium levels was not clear because of the similar biomass distributions. The five megagrams per hectare division could be explained by the vegetation type. Woody vegetation was typically found in high level control plots, supported by high biomass levels. Woody vegetation accumulates biomass as secondary growth in the stems. Broadleafs and grasses were typically found in the medium and low levels. Broadleafs and grasses will produce aboveground biomass for the growing season and die back during the dormant season. However, there were a few control plots with higher than five megagrams per hectare biomass with broadleaf or grass vegetation. This could be explained by late summer growth captured at the end of the growing season biomass harvest.

Improving the visual assessment UCV level classification to a finer scale, more categories, could improve the prediction ability of the visual assessment to predict the biomass amount. Currently, the visual assessment is not able to detect differences in UCV biomass for low to medium vegetation levels. The visual assessment could also be improved by characterizing the UCV type in more detail. This is especially true for the woody vegetation category, including trees, shrubs and vines. Dividing the woody classification into non-pine trees, volunteer pine, woody vines and evergreen shrubs could improve the prediction ability. While these vegetation types may all have a woody component, arborescent species have a different growth form than vines and shrubs. Evergreen trees and shrubs retain their leaves while deciduous trees and shrubs lose their leaves. These differences will create differences in aboveground biomass.

As is, the visual assessment produced prediction equations with moderately strong accuracy, for a biological system. The best biomass prediction by vegetation level was for broadleaf vegetation with an R-squared of 0.85, followed by grass vegetation at 0.69 and lastly, woody vegetation at 0.36. This is in contrast to a study in the northwest, where Suchar and Crookston (2010) tested herbaceous biomass indices and vegetative covers and found no significant differences. Overall, they found no significant relationships in understory percent cover, percent canopy cover and biomass indices for 129 ecoclasses analyzed.

Similar to the visual assessment, the understory biomass was not strongly influenced by soil type. The biomass distribution of vegetation type and level across mineral and organic showed no clear trends. In thinned stands, biomass ranged from 1.4 to 4.9 megagrams per hectare on organic soils and 1.8 to 24.3 megagrams per hectare on mineral soils. One thinned control plot on mineral soil had no competing vegetation due to a recent herbicide application. On unthinned stands, biomass ranged from 1.1 to 16.7 megagrams per hectare to on organic soils and 0.7 to 10 megagrams per hectare on mineral soils. The high biomass levels (16.7 and 24.3 Mg ha^{-1}) were outliers within the distribution. The vegetation is adapted to the soil conditions and responds to additional nutrition, from fertilization, by accumulating biomass.

Comparing loblolly pine leaf area index (LAI) in control versus treatment plots, thinned stands generally had lower LAI than unthinned. This is expected because loblolly pine canopy requires time to respond to thinning treatments. LAI values were within the normal range of loblolly pine leaf area in the SEUS. Peduzzi et al. (2010) measured similar loblolly pine values, averaging 2.5 meters squared of leaves per meters squared of ground in winter (February to March).

Comparisons of the competing vegetation biomass as a function of loblolly pine LAI indicated a limit for understory biomass in relation to pine LAI. As expected when pine LAI is high, competing vegetation biomass is low (Stransky et al. 1986; Miller et al. 2003a; Peduzzi et al. 2010). High loblolly LAI values suggest the pine canopy is capturing photosynthetically active radiation and shading the understory. Closed canopies occur prior to thinning and many years after. When pine LAI is low, competing vegetation biomass is high. Gaps in the canopy allow sunlight to reach the forest floor. Here, the understory vegetation is capturing the radiation.

In this study, unthinned stands had higher LAI values and corresponding lower understory biomass levels compared to thinned stands. Thinned stands only had a maximum LAI of 2 meters squared of leaves per meters squared of ground while unthinned had a maximum of 3.5 meters squared of leaves per meters squared of ground. Specifically at Hofmann Forest, when loblolly pine LAI is 1.5 meters squared of leaves per meters squared of ground or lower, competing vegetation is going to be present at high levels and will generally be woody. When pine LAI is greater than 3 meters squared of leaves per meters squared of ground, competing vegetation is present at low levels. Pine LAI is controlling how much competing vegetation biomass is in the understory.

NUTRITIONAL ANALYSIS

3. Relative nutrient uptake by understory competing vegetation (UCV) in relation to overstory loblolly pine nutrient uptake at Hofmann Forest, NC

3.1 Introduction

As previously mentioned, nutrition is often the main limiting resource in Lower Coastal Plain environments (Neary et al. 1990; Fox et al. 2007a). The soils of the pocosins are rich in organic matter, with low pH (acidic), generally wet and retain water, but are lacking in mineral nutrition, a result of leaching. Fertilization is commonly applied to pine plantations to improve the soil nutritional status. Drainage is also needed on wet sites to improve the mineral nutrient availability. At Hofmann Forest, site index can be increased on poorer sites with the addition of phosphorous (P) and drainage (Catts, 2010). The known suite of minerals needs for loblolly pine survival, growth and reproduction, include macro-nutrients (P; nitrogen [N]; potassium [K]; calcium [Ca]; magnesium [Mg]; sulfur [S]) and micro-nutrients (boron [B]; chloride [Cl]; copper [Cu], iron [Fe], manganese [Mn], molybdenum [Mo], zinc [Zn]). Macro-nutrients are needed in larger concentrations, for more physiological processes, than micro-nutrients. Loblolly pine plantations in other environments may need different mineral fertilization depending on the soils. In certain soil types, K, Ca, Cu and B can be deficient and significant growth increases have been observed (Fox et al. 2007a). Enriching plant available nutrition in the soil, with fertilization, improves loblolly pine growth by providing the mineral nutrients for physiological processes.

Loblolly pines grow at different rates during the rotation. The competing vegetation types and levels also vary with loblolly canopy development. Therefore, the response from fertilization will vary based on when the fertilization is applied (age and time of year), what vegetation is present, climate, soil water availability and the soil type. Studies on the effects of applying fertilizer on early pine growth (Neary et al. 1990; Fox et al. 2007a), also through canopy closure (Fox et al. 2007a; Albaugh et al. 2012b), have been observed. On a piedmont site after a harvest, a naturally regenerated loblolly pine stand, nutrient accretion was primarily in herbaceous plants during the first two years (Cox and Van Lear, 1984). After five growing seasons, P, N and K in standing biomass was greater than or equal to previous pine plantation of 41 years. Specifically at Hofmann Forest, after thinning and vegetation control, fertilization may be applied on specific sites where needed; 225 kilograms N (175 kg Urea) and 27 kilograms P (57 kg DAP) per hectare (Catts, 2010). When the twin plots were installed at Hofmann Forest in 2011, the treatment plots received, and continue to receive as needed, additional fertilization to reduce any potential nutrient limitations. The specifics on the nutrients and the rate of application can be found in Appendix D (FPC, 2010).

During midrotation, vegetation control and fertilization are associated with thinning activities. The idea is to release the target species (loblolly pine) to grow at the maximum rate. Thinning occurs when loblolly pine trees are large enough (15 to 25 cm diameter class), with closed canopies, and the intraspecific competition among loblolly pines are high. By thinning, forest managers choose trees to remove, providing additional space and resources for the remaining trees to thrive. Competing vegetation is often removed at this time to improve the likelihood water and nutrition will be retained by the desired remaining crop trees. The nutrient competition between pine and competing vegetation (hardwoods, shrubs) can be intense at high numbers, but the nutrients accumulated by the competing vegetation would not be used by loblolly in their absence (Schultz, 1997).

Thinning and vegetation control improves the water availability in the soil by lowering the moisture demand from unwanted plants and increasing the precipitation reaching the forest floor through the newly created canopy gaps. Then, to promote the remaining pines to grow at optimum rates, fertilization is applied providing the resources necessary to produce more leaves. A greater leaf area leads to more pine productivity. Midrotation plantations require fertilization because N and P are limiting growth at crown closure; leaf area and light use efficiency directly affect the growth (Fox et al. 2007a). Foliage responds more quickly to changes in soil nutrient levels and high concentrations of nutrients are found in leaves, relative to other plant tissues, simplifying nutritional analyses (Miller and Glover, 1991). Plant nutrition is determined, in part, by the uptake of nutrients by the roots. Changes occurring in the root system can cause rapid change in foliar nutrient levels in concentrations of macro- and micro-nutrients; changes in micro-nutrients may have been observed before macro-nutrients, due to the relative abundance of each (Miller and Glover, 1991).

Loblolly pine nutrition is reasonably understood (Fox et al. 2007a), but there are still questions on how to improve pine resource availability with silvicultural practices during midrotation. For instance, is combined vegetation control and fertilization needed after thinning or could one be substituted for the other (Albaugh et al. 2012b)? Another question is regarding what vegetation is actually benefitting from the additional nutrition, the competing vegetation or loblolly pine. The objectives of this project are to quantify the relative nutrient content in the competing vegetation component during midrotation. The role competing vegetation plays in nutrient cycling and storage is important, but mostly unquantified, in loblolly pine ecosystems (Schultz, 1997). The twin plots at Hofmann offer a unique opportunity to compare the UCV nutritional status on mineral versus organic soils across the landscape in the same climate. Stands have been thinned while others have not, allowing for comparisons and contrasts to be made before and after thinning. Quantifying how much nutrition in loblolly pine canopy is vital. Knowing the relative nutritional status of UCV can assist forest managers in knowing how nutritionally important the understory vegetation is during midrotation.

3.2 Objectives

1. Quantify the relative nutrient content (macro- and micro-nutrients) of understory competing vegetation and overstory loblolly pine during midrotation.
2. Relate nutrient content to the visual assessment
3. Relate nutrient content to competing vegetation biomass.
4. Express relative nutrient content in relation to loblolly pine canopy demands.

3.3 Methods and Materials

The understory competing vegetation (UCV) sample harvested from the 40 Hofmann Forest control plots, weighing approximately one kilogram each, were returned the FPC lab at NCSU. The sample was sorted into woody (stems; bark) and canopy (foliage) tissues. Sorted subsamples were transferred to paper bags and oven dried at 65 to 70°C until constant weight. From the *Standard methods for forest herbicide research*, Southern Weed Science Society, plant samples are prepared for nutrient analyses by using 10 to 15 grams of green foliage per plant, then oven dried (70°C) to a constant weight, ground and sieved for preparation of analyses (Miller and Glover, 1991). Each subsample was ground to pass a one millimeter screen in a Wiley Mill grinder. Dry ground weights used for analysis ranged from 10 to 80 grams per control plot, depending on how much green material was harvested. The samples were analyzed for macro- and micro-nutrients (N, P, K, Ca, Mg, S and B, Cu, Fe, Mn, Zn) by the standard procedures at Waters Agricultural Laboratories, Inc. in Camilla, GA. Extra vegetative material from the sample was ground and archived by NCSU FPC in Raleigh, NC.

Loblolly pine nutrition was determined from sampling foliage in 12 treatment and control plots at Hofmann Forest, NC. The 12 twin plots were chosen based on the treatment and control LAI values, to cover the full range of LAI values and sample from each competing vegetation level (Appendix G). The range of LAI values was divided into four groups. Then three plots were chosen inside each group. Three low, three medium, five high and the one none vegetation level control plots were sampled. On March 17^{th} and 18^{th} 2014 loblolly pine branches were harvested from the uppermost laterals, containing a full year's complement of foliage, from three dominant pine trees in each of the selected twin plots (Figure 20). A shotgun was used to shoot down the branches. Needles were chosen from the first flush produced during previous growing season, located on primary lateral branches in the upper one third of the live crown. Whole, healthy, intact pine fascicles where placed in labeled Ziploc bags, weighed and kept in cooler until returned to the FPC lab at NCSU in Raleigh, NC.

In the lab, a composite pine foliage sample was sorted consisting of exactly 90 fascicles, 30 fascicles from each of the three dominant loblolly pine trees (Figure 20). The fascicles were carefully dried and removed of contaminants. Then the needles were transferred to paper bags and oven dried at 65 to 70°C until constant weight, ground and sent to Waters Agricultural Laboratories, Inc. in Camilla, GA for nutritional analysis. The returned analysis reported macro-nutrients by percentage (%) and micro-nutrients in parts per million (ppm). For the UCV, nutrient values were expanded to plot area by multiplying dry weight biomass by dry weight concentrations and then converted to kilograms per hectare. Each control plot was computed individually. Canopy and woody components were analyzed separately and then summed to attain the total nutrient content in the understory vegetation for each control plot. Loblolly pine dry foliage biomass was estimated from LAI and projected specific leaf area (5 m^2 leaves kg^{-1} leaves) (Peduzzi et al. 2010). Nutrient content was then calculated in the same manner as UCV.

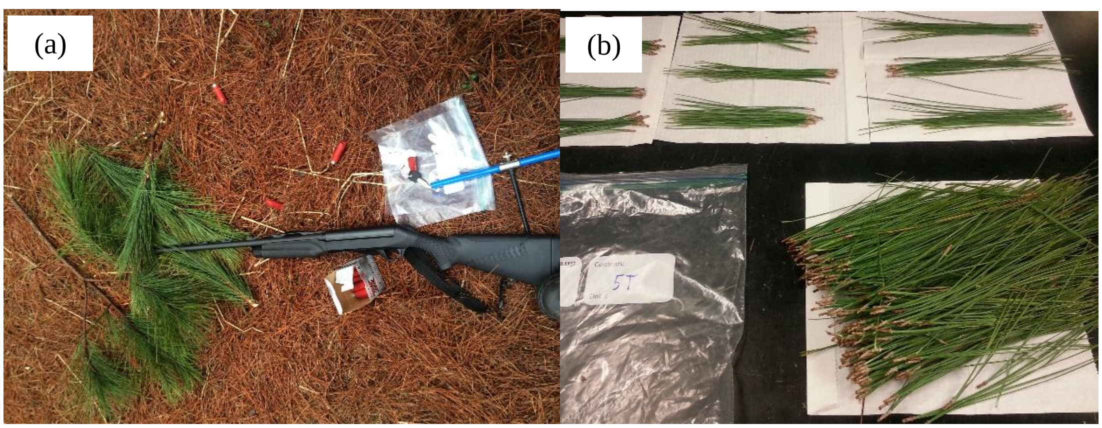


Figure 20: Loblolly pine foliage sampling (a) from dominant trees on 12 twin plots at Hofmann Forest on March 17-18, 2014. Pine fascicles being counted, cleaned and dried (b) in the FPC lab at NCSU Raleigh, NC.

3.4 Results

3.4.1 Understory Competing Vegetation (UCV) Nutrition

N is important in how plant biomass is partitioned. This is why N fertilization is applied so often to improve plant growth. The UCV biomass had a strong and positive correlation (0.96) to the N content in the competing vegetation (Figure 21). A linear regression was applied with a strong R-squared value of 0.92, indicating the biomass is a good predictor to how much N is in the vegetation.

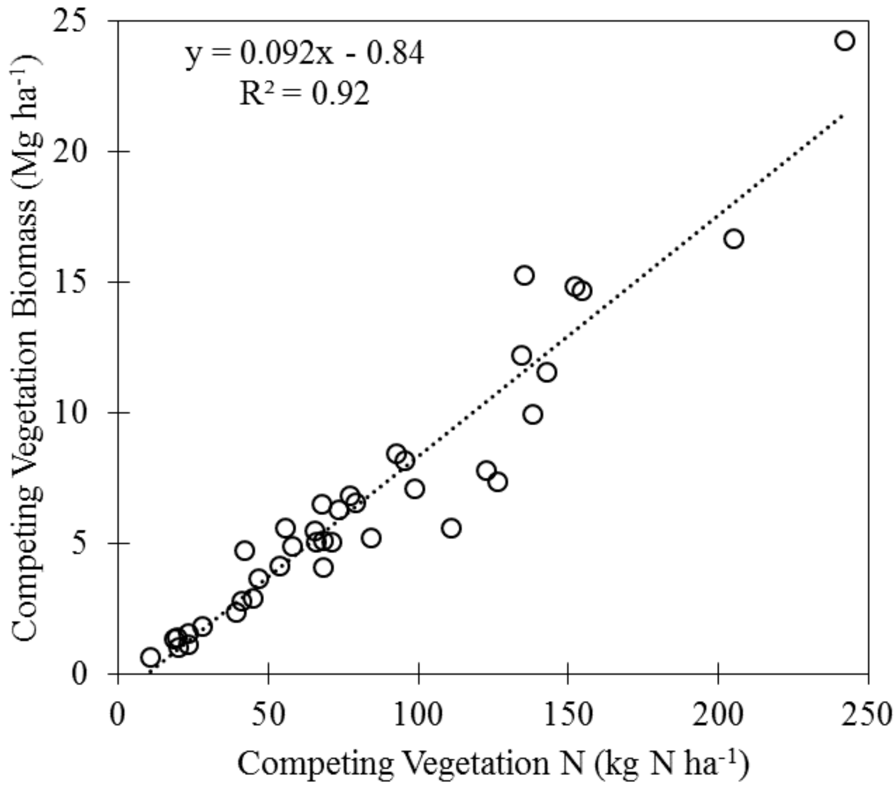


Figure 21: Relationship of nitrogen (N) content (kg N ha^{-1}) to competing vegetation biomass (Mg ha^{-1}). Aboveground biomass was harvested in September 2013 in the 39 control plots at Hofmann Forest, NC. The same biomass sample was used for nutritional analysis conducted by the standard procedures at Waters Agricultural Laboratories, Inc. in Camilla, GA.

N and P are two nutrients frequently applied as fertilizer to maximize growth and eliminate deficiencies in the soil. UCV N ranged from 19.2 to 242.0 kilograms N per hectare with a mean of 86.5 kilograms N per hectare in thinned control plots. In unthinned stands, UCV N ranged from 10.5 to 204.8 kilograms N per hectare with a mean of 78.5 kilograms N per hectare. UCV P averaged 5.3 and 4.7 kilograms P per hectare in thinned and unthinned stands respectively. UCV P ranged from 1.3 to 19.0 kilograms P per hectare in thinned control plots and 0.63 to 13.7 kilograms N per hectare. Descriptive statistics for all the macro- and micro-nutrients can be found in Appendix H.

3.4.2 UCV Nutrition on Organic and Mineral Soils

The UCV nutrient content was determined to investigate how much each level and each vegetation type had accumulated. Table 19 reports the mean nutrient content in aboveground competing vegetation by soil type, vegetation level and dominant vegetation type. Single observations were reported when there was only one control plot per soil, vegetation level and type. Standard errors are shown in italics, under the mean values. Standard error was calculated for nutrient content means in groupings with more than one control plot ($n > 1$). Five visual assessment groupings had only one control plot ($n = 1$), therefore the value is reported with an associated error calculated from the average error from two sets of standards included in the nutritional analysis. The standards were dry, ground competing vegetation material from a control plot. Standard errors were calculated using the actual sample values with the standard values ($n = 3$). The standard errors are the same for all single observation groupings. A second standard was also included in the analysis consisting of a dry plant material mixture from all the control plot canopies. Waters Agricultural Laboratories, Inc. was also unaware of this standard, because it was also indistinguishable from the rest of the samples. Error was calculated from the average standard error from these two standards.

Table 19: Mean (or single) competing vegetation nutrient content sampled in the control plots at Hofmann Forest. The relative percent for each nutrient was expanded using the understory biomass harvested in September 2013. Mineral soils were Spodosols, Ultisols and an Inceptisol and organic soils were Histosols. Nutrient contents are by competing vegetation level and dominant vegetation type. Standard error (SE), in italics, and number of observations (n) are provided. All nutrient analysis was conducted by the standard procedures at Waters Agricultural Laboratories, Inc. in Camilla, GA.

				Macro-nutrients (kg ha^{-1})						**Micro-nutrients (g ha^{-1})**				
	Level	**Dominant Type**		**N**	**P**	**K**	**Mg**	**Ca**	**S**	**B**	**Zn**	**Mn**	**Fe**	**Cu**
Mineral Soil	**Low**	**Broadleaf**		10.53	0.63	3.95	1.00	4.09	0.55	8.66	30.75	154.50	28.88	3.52
		(n = 1)	***SE***	*0.103*	*0.004*	*0.017*	*0.009*	*0.015*	*0.002*	*1.317*	*0.225*	*1.952*	*2.656*	*0.568*
	Medium	**Broadleaf**		24.54	1.56	10.33	3.08	9.41	1.46	29.81	67.27	245.59	72.93	11.56
		(n = 3)	***SE***	*1.561*	*0.139*	*1.160*	*0.551*	*1.279*	*0.251*	*7.131*	*8.237*	*87.334*	*6.570*	*2.342*
		Grass		39.00	2.09	13.73	3.71	10.78	2.32	41.62	125.65	208.83	123.77	18.05
		(n = 1)	***SE***	*0.103*	*0.004*	*0.017*	*0.009*	*0.015*	*0.002*	*1.317*	*0.225*	*1.952*	*2.656*	*0.568*
	High	**Broadleaf**		74.75	4.66	28.54	8.97	29.92	5.36	87.72	180.66	1366.12	239.69	29.31
		(n = 2)	***SE***	*9.258*	*0.298*	*1.573*	*1.265*	*10.107*	*1.511*	*23.600*	*0.846*	*1049.943*	*50.372*	*0.848*
		Grass		134.21	8.49	67.82	15.68	64.40	8.44	147.95	293.51	839.85	362.69	47.18
		(n = 1)	***SE***	*0.103*	*0.004*	*0.017*	*0.009*	*0.015*	*0.002*	*1.317*	*0.225*	*1.952*	*2.656*	*0.568*
		Woody		109.80	6.05	42.13	14.78	43.75	6.56	125.60	269.02	931.60	469.26	53.83
		(n = 11)	***SE***	*17.447*	*1.417*	*9.585*	*2.346*	*5.230*	*0.927*	*23.077*	*39.667*	*174.776*	*146.314*	*8.356*
Organic Soil	**Low**	**Broadleaf**		19.19	1.32	7.76	1.87	6.65	1.18	22.19	81.53	246.06	46.19	5.27
		(n = 1)	***SE***	*0.103*	*0.004*	*0.017*	*0.009*	*0.015*	*0.002*	*1.317*	*0.225*	*1.952*	*2.656*	*0.568*
		Grass		32.14	1.58	11.17	3.23	12.51	1.70	25.77	60.49	248.95	72.73	10.22
		(n = 2)	***SE***	*12.517*	*0.300*	*0.820*	*1.310*	*9.096*	*0.735*	*14.559*	*18.442*	*33.380*	*29.362*	*4.430*
		Woody		40.94	2.18	15.87	2.28	13.45	2.08	37.53	77.59	221.78	100.47	14.74
		(n = 1)	***SE***	*0.103*	*0.004*	*0.017*	*0.009*	*0.015*	*0.002*	*1.317*	*0.225*	*1.952*	*2.656*	*0.568*
	Medium	**Grass**		98.35	4.58	33.35	12.42	51.67	6.69	99.16	242.84	828.25	331.75	30.62
		(n = 2)	***SE***	*27.649*	*2.053*	*10.121*	*2.318*	*18.334*	*2.148*	*13.506*	*64.570*	*65.623*	*139.089*	*3.498*
		Woody		47.87	2.02	18.57	4.91	19.90	2.81	69.08	93.57	468.68	127.29	24.76
		(n = 3)	***SE***	*17.515*	*0.747*	*8.904*	*1.656*	*9.445*	*1.002*	*33.924*	*35.184*	*250.176*	*53.046*	*10.955*
	High	**Broadleaf**		82.80	7.68	44.22	8.07	16.16	6.05	50.07	224.54	645.48	187.26	32.42
		(n = 4)	***SE***	*13.196*	*2.298*	*7.446*	*1.813*	*2.706*	*1.332*	*11.905*	*67.119*	*116.765*	*25.027*	*6.031*
		Woody		111.15	7.08	39.43	15.45	58.52	7.84	148.02	424.41	1337.40	330.33	51.96
		(n = 7)	***SE***	*20.753*	*1.194*	*5.403*	*3.451*	*12.458*	*1.507*	*23.737*	*145.410*	*206.271*	*55.378*	*9.220*

3.4.3 UCV Nutrition and Species Characterization

From the nutritional analysis and the visual assessment, the nutrient content in the UCV species can be determined. Nutrient content and aboveground biomass measurements were made collectively for dominant and co-dominant species. While reporting the individual nutrient contents and biomass for each control plot can provide specific details about a site, the goal here to consider the species with the most and least nutrient content for the entire control plot. Since the dominant species consisted of the bulk of the biomass and covered the majority of the growing space, the nutrient contents are reported considering only the dominant competing vegetation species. Table 20 reports the mean nutrient content analyzed from the competing vegetation biomass. All control plots with the same dominant species were pooled to calculate the mean nutrient content. Eight control plots had a dominant species only occurring once and the single observation is reported. The number of control plots for each dominant species is listed (n) as well as the vegetation type from the visual assessment. Species biomass is the UCV biomass harvested at the end of the 2013 growing season, expanded to the entire control plot. Loblolly pine LAI was measured in the control plots in February 2014.

The highest N content was found in two control plots with *Persea palustris*, a woody species (Table 20). The biomass was relatively high (12.2 Mg ha^{-1}) and loblolly pine LAI low (0.9 m^2 m^{-2}). The lowest N content was in *Pteridium aquilinum*, also in two control plots, a broadleaf species with low biomass (1.1 Mg ha^{-1}) and a higher pine LAI (2.8 m^2 m^{-2}). The top three control plots with the highest N content were dominated by woody vegetation. The lowest N content was in two broadleaf and two grass dominated sites. The two most dominant species *Ilex coriacea* (n = 6) and *Eupatorium capillifolium* (n = 7) had 90.5 and 66.5 kilograms N per hectare. Generally, the other nutrients concentrations in the competing vegetation followed a similar ranking as with N.

Table 20: Mean or single observation values for nutrient content in the Hofmann Forest control plots by dominant species. The nutrient content and biomass values include both the dominant and co-dominant species combined. The dominant species are listed from the highest nitrogen content to the lowest. The number of control plots with each dominant species is provided (n). When sample size was greater than one, means are reported. The nutrient content for the single control plots are reported. Species biomass refers to understory competing vegetation harvested in September 2013. Loblolly pine leaf area index (LAI) is provided and was measured in February 2014.

					Macro-nutrients (kg ha^{-1})						Micro-nutrients (g ha^{-1})				
Dominant Species	**Type***	**n**	**Species Biomass (Mg ha^{-1})**	**Pine LAI (m^2 m^{-2})**	**N**	**P**	**K**	**Mg**	**Ca**	**S**	**B**	**Zn**	**Mn**	**Fe**	**Cu**
Persea palustris	W	2	12.2	0.9	163.5	8.7	42.6	23.2	79.4	12.7	180.3	387.9	1349.2	426.7	64.9
Lyonia lucida	W	1	14.9	1.4	152.0	10.6	60.3	26.4	78.0	9.1	220.0	317.1	1683.2	507.9	74.6
Pinus taeda	W	4	13.9	1.0	149.2	10.0	63.5	17.9	54.9	8.2	193.1	344.7	1237.2	477.0	71.2
Andropogon virginicus	G	1	12.2	1.0	134.2	8.5	67.8	15.7	64.4	8.4	148.0	293.5	839.9	362.7	47.2
Carex glaucescens	G	2	6.2	2.1	98.4	4.6	33.4	12.4	51.7	6.7	99.2	242.8	828.3	331.8	30.6
Ilex coriacea	W	6	8.6	1.7	90.5	4.5	32.8	11.0	45.6	5.6	124.3	421.8	1163.9	254.7	47.6
Cyrilla racemiflora	W	1	6.9	1.3	77.0	5.9	28.6	12.4	29.5	4.6	92.5	144.4	330.0	228.2	43.3
Eupatorium capillifolium	B	7	4.2	1.7	66.5	5.5	32.8	7.1	17.6	4.9	54.7	174.1	801.9	168.2	26.3
Gordonia lasianthus	W	1	5.1	2.4	65.5	3.9	27.8	6.1	22.8	4.2	61.6	168.4	1210.5	184.5	27.6
Smilax laurifolia	B	1	5.5	2.2	65.5	5.0	27.0	7.7	19.8	3.9	64.1	181.5	316.2	189.3	30.2
Rubus sp.	W	4	4.4	2.2	60.9	3.1	22.4	8.1	25.9	4.2	59.3	104.5	477.6	523.9	30.9
Aralia spinosa	W	1	5.6	1.7	55.5	2.4	24.6	11.5	29.3	3.3	65.6	365.2	922.3	210.8	30.0
Acer rubrum	W	2	4.9	0.9	55.1	2.4	22.2	7.5	24.3	3.8	53.3	95.1	275.2	219.9	22.7
Arundinaria gigantea	G	1	2.4	1.8	39.0	2.1	13.7	3.7	10.8	2.3	41.6	125.7	208.8	123.8	18.1
Dichanthelium commutatum	G	2	2.0	2.3	32.1	1.6	11.2	3.2	12.5	1.7	25.8	60.5	249.0	72.7	10.2
Smilax glauca	B	1	1.4	1.3	19.2	1.3	7.8	1.9	6.6	1.2	22.2	81.5	246.1	46.2	5.3
Pteridium aquilinum	B	2	1.1	2.8	16.8	1.0	6.0	1.5	6.8	0.9	13.4	45.8	138.1	54.5	6.3

* B = broadleaf; G = grass; W = woody.

3.4.4 UCV Nutrition with Pine Nutrition and LAI

The nutrient content has been established for the UCV. Comparisons between UCV and overstory loblolly pine mean nutrient content, biomass and LAI can be found in Table 21. The data is further divided into thinned versus unthinned control plots. Understory LAI was not measured. The standard errors for the means are included, in italics. The loblolly pine canopy biomass was greater in unthinned than thinned control plots. Interestingly, loblolly pine canopy biomass was greater in the control plots versus the treatment plots. UCV biomass averaged higher in thinned control plots, with the lower overstory pine biomass. As expected, loblolly pine LAI was higher in unthinned plots, where the canopy biomass was also higher. For macro-nutrients in thinned plots, the UCV average nutrient content was higher than treatment and control pine canopy nutrient content. Unthinned stands did not have a clear distinction in macro-nutrient content in the understory and pine components. N, P, K and S nutrient content was larger in loblolly pine canopies than UCV, but the difference was small for many of these nutrients. Mg and Ca were greater in the UCV component. The largest difference in macro-nutrient content in unthinned stands was seen with N, Mg and Ca. There was 93.3 and 86.6 kg N per hectare in the control and treatment pine canopies, respectively, compared to 78.5 kg N per hectare in the UCV. Mg and Ca nutrient content was double or more in UCV compared to pine canopy. A similar pattern was observed for micro-nutrient content. Thinned plots had higher concentrations in UCV for all micro-nutrients. In unthinned plots, Zn, Mn, Fe and Cu mean nutrient contents were above pine canopy content. B was the greatest in the control pine canopies.

Table 21: Mean understory biomass and nutrient content comparisons to overstory loblolly pine canopy biomass, leaf area index (LAI) and nutrient content for both control and treatment plots, in thinned and unthinned stands at Hofmann Forest, NC. Standard error is included in italics for each mean. Understory biomass was harvested in September 2013 and used for the corresponding nutrient content. Loblolly pine LAI was measured in February 2014 and pine foliage samples collected in March 2014. These samples were used to determine nutrient content in the overstory canopy. All nutritional analysis was conducted by the standard procedures at Waters Agricultural Laboratories, Inc. in Camilla, GA.

	Thinned			**Unthinned**		
	Control		**Treatment**	**Control**		**Treatment**
	Understory	**Pine Canopy**	**Pine Canopy**	**Understory**	**Pine Canopy**	**Pine Canopy**
Biomass	6912.73	2414.12	2245.88	6314.95	4024.35	3909.57
(kg ha^{-1})	*154.08*	*162.47*	*195.80*	*94.35*	*252.65*	*263.23*
LAI	na	1.21	1.12	na	2.01	1.95
(m^2 m^{-2})		*0.08*	*0.10*		*0.13*	*0.13*
Macro-nutrients						
(kg element ha^{-1})						
N	86.52	44.09	48.92	78.45	93.28	86.59
	14.65	*8.43*	*10.55*	*10.35*	*13.35*	*11.17*
P	5.33	2.76	3.51	4.72	6.43	6.92
	1.11	*0.44*	*0.52*	*0.74*	*0.54*	*0.59*
K	35.44	10.48	13.39	30.05	30.42	27.77
	7.53	*1.41*	*2.28*	*3.72*	*1.75*	*1.81*
Mg	10.63	2.27	2.40	10.03	5.03	4.26
	1.92	*0.43*	*0.36*	*1.64*	*0.52*	*0.42*
Ca	32.81	4.48	5.67	35.05	11.60	9.48
	5.09	*0.97*	*0.84*	*6.13*	*1.76*	*1.35*
S	5.36	2.91	3.57	5.23	6.30	6.25
	0.76	*0.40*	*0.44*	*0.79*	*0.61*	*0.66*
Micro-nutrients						
(g element ha^{-1})						
B	99.33	42.62	49.45	87.33	103.50	90.50
	19.13	*8.15*	*9.21*	*13.17*	*9.87*	*9.54*
Zn	194.58	80.90	92.13	251.07	207.17	182.60
	31.40	*17.90*	*19.84*	*53.43*	*19.65*	*26.35*
Mn	778.06	141.85	202.20	801.86	405.50	394.54
	167.10	*49.29*	*45.68*	*121.39*	*73.96*	*97.86*
Fe	263.47	120.47	140.24	285.16	260.75	244.61
	46.58	*14.14*	*20.02*	*76.34*	*31.07*	*23.22*
Cu	37.68	10.60	12.62	35.68	18.76	14.27
	6.98	*1.57*	*3.07*	*5.00*	*1.61*	*1.79*

Comparing the nutrient content in loblolly pine foliage to the nutrient content in the total UCV component provides insight on where the mineral nutrients from the soil and fertilization are accumulating. A simple visual way to see this relationship is with one to one (1:1) lines (Figure 22-23). The nutrient content in loblolly pine canopies and UCV components have equal axes with a 45° angled line, starting at zero, drawn in. Any points below the line have higher nutrient concentrations in the UCV component than in loblolly pine foliage. Any points above the line have a higher nutrient content in loblolly pine foliage than the UCV. The macro-nutrient (N, P, K, Mg, Ca, S) contents are found in Figure 22 and micro-nutrients (B, Zn, Mn, Fe, Cu) contents in Figure 23. Each figure includes thinned versus unthinned stands. Thinned stands are shown as solid circles and unthinned stands as empty triangles. Loblolly pine foliage was only sampled from 12 twin plots (see materials and methods), and one of them had no competing vegetation. Figures 22 and 23 make comparisons for these 12 twin plots because of the direct measurements.

Comparisons for the twin plot with no competing vegetation in the control cannot be made because nutrient content could only be determined for pine foliage. Interestingly, in thinned stands K, Mg and S content was greater in the competing vegetation than loblolly pine foliage, but there was no correlation (-0.04 to -0.06) (Figure 22-23). The same was true for N except for one twin plot located slightly above the 1:1 line, no correlation (0.04). Ca and P had one thinned twin plot with greater concentrations in the competing vegetation. The rest had higher concentrations in competing vegetation, weakly correlated (0.43 and -0.32). Unthinned stands had four control plots with higher nutrient content pine foliage and three with higher nutrient content in competing vegetation for N, K, Mg, Ca and S. The relationships for N, K, Mg, Ca and S were weakly to somewhat correlated, -0.65, -0.64, -0.49, -0.63 and -0.58, respectively. P nutrient content was greater in loblolly pine foliage for all control plots except one, somewhat correlated -0.57. Micro-nutrients in thinned and unthinned stands had similar patterns as the macro-nutrients. The relationship between nutrient content in UCV and loblolly pine foliage were mostly not correlated to weakly correlated (< ±0.75) for B, Mn, Fe and Cu. B had the only relationship in nutrient content somewhat correlated (-0.80) in unthinned stands. B in thinned stands was weakly correlated (0.45) and favored UCV.

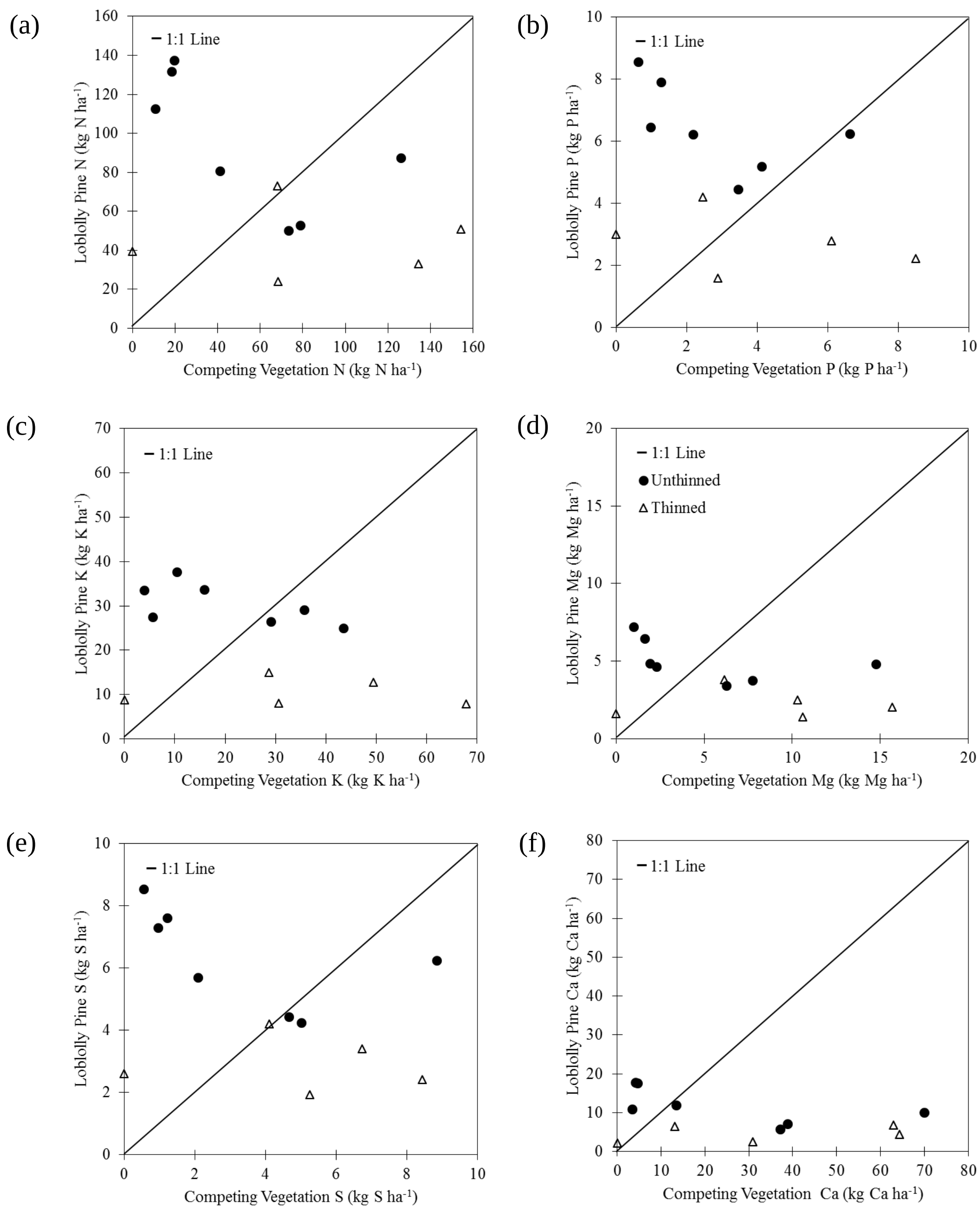


Figure 22: Macro-nutrient content comparison between overstory loblolly pine foliage and understory competing vegetation in the control plots at Hofmann Forest, NC. Nutrient content was determined from loblolly pine foliage collected in March 2014 and competing vegetation in September 2013. The macro-nutrients nitrogen (a), phosphorous (b), potassium (c), magnesium (d), sulfur (e) and calcium (f) are shown. Thinned stands are shown as solid circles and unthinned stands as empty triangles.

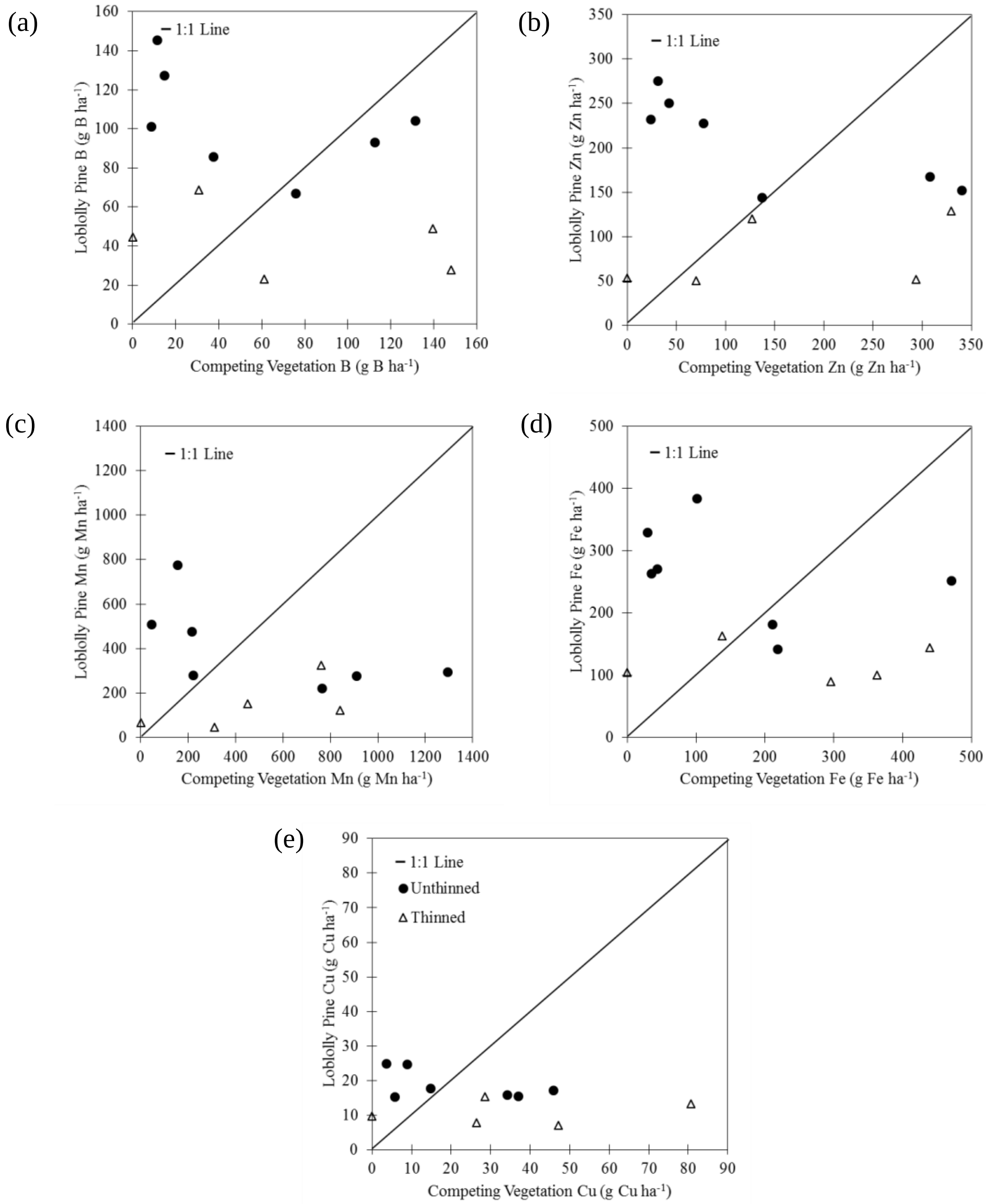


Figure 23: Micro-nutrient content comparison between overstory loblolly pine foliage and understory competing vegetation in the control plots at Hofmann Forest, NC. Nutrient content was determined from loblolly pine foliage collected in March 2014 and competing vegetation in September 2013. The micro-nutrients boron (a), zinc (b), manganese (c), iron (d) and copper (e) are shown. Thinned stands are shown as solid circles and unthinned stands as empty triangles

The nutritional analysis from the loblolly pine foliage in both the treatment and control plots allowed for comparisons of loblolly pine canopy with and without competing vegetation and additional fertilization. The macro- and micro-nutrient percent in control pine canopies was compared to treatment pine canopies (Figure 24-25). One to one lines are used for comparisons. In Figure 24d, Mg and S had similar nutrient concentration levels, plotted together. In Figure 25d, Zn and Fe also had similar nutrient content, graphed together. There were no significant trends in pine nutrient content considering thinning or soil type because the distribution of each was scattered above and below the 1:1 line. No trends were observed therefore, a direct comparison is made between the nutrient percent in each pine canopy. The strongest correlations in macro-nutrient content between control and treatment pine canopies were positive for N (0.69) and K (0.70). Mg and P were negatively and weakly to not correlated, -0.24 and -0.17, respectively. Ca had no correlation (0.06). S was somewhat positively correlation (0.59). For the micro-nutrients, all relationships were positive and ranged from not correlated to somewhat correlated. The correlations were 0.51, 0.10, 0.54, 0.07 and 0.27 for B, Zn, Mn, Fe and Cu, respectively.

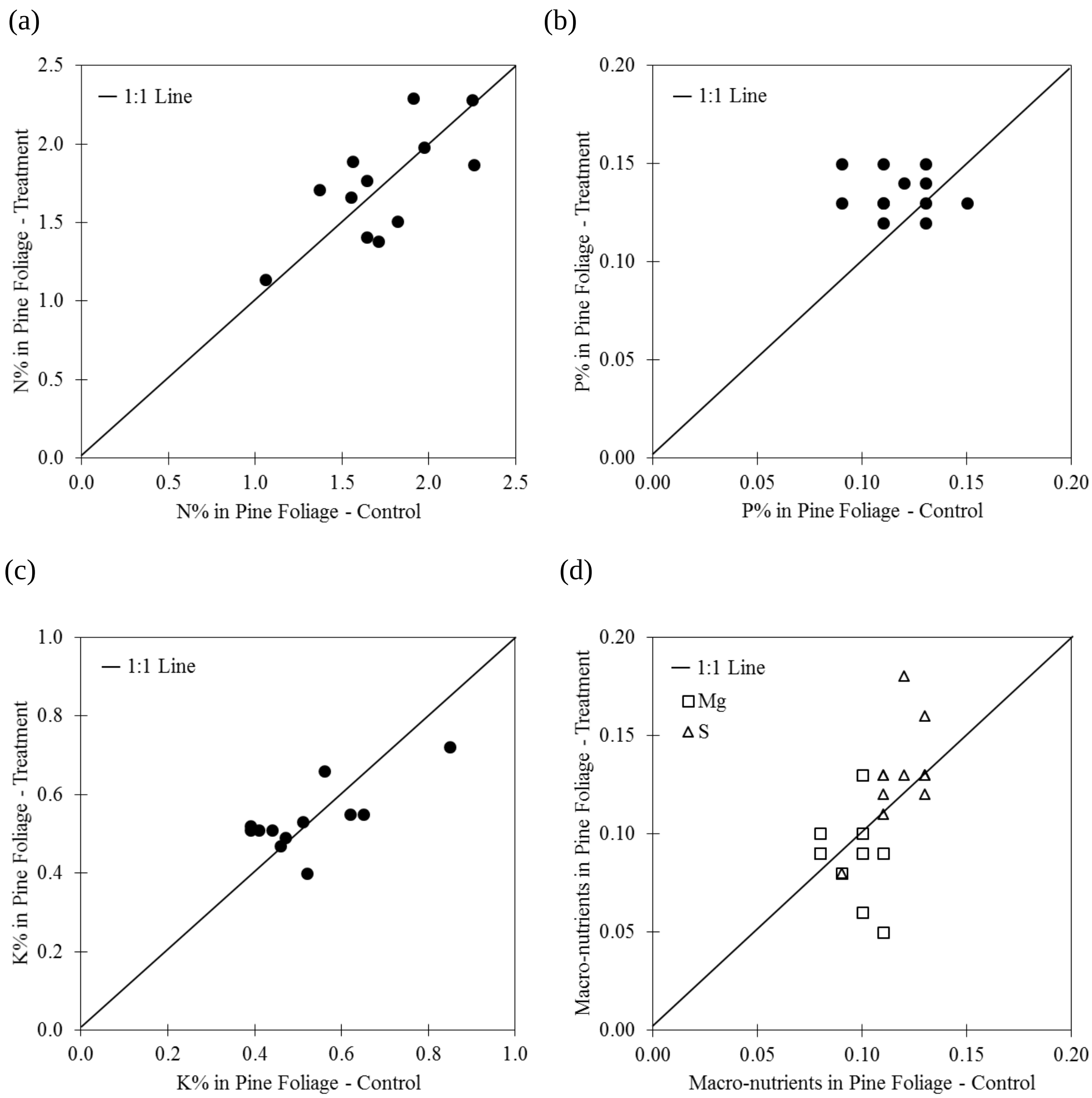


Figure 24: Macro-nutrients nitrogen (a), phosphorous (b) and potassium (c) analyzed from loblolly pine foliage collected from dominant trees in the control and treatment plots at Hofmann Forest, NC in March 2014. Magnesium and sulfur (d) are also shown together. All values are expressed as the percent (%) of each nutrient obtained from ground, dry pine needles.

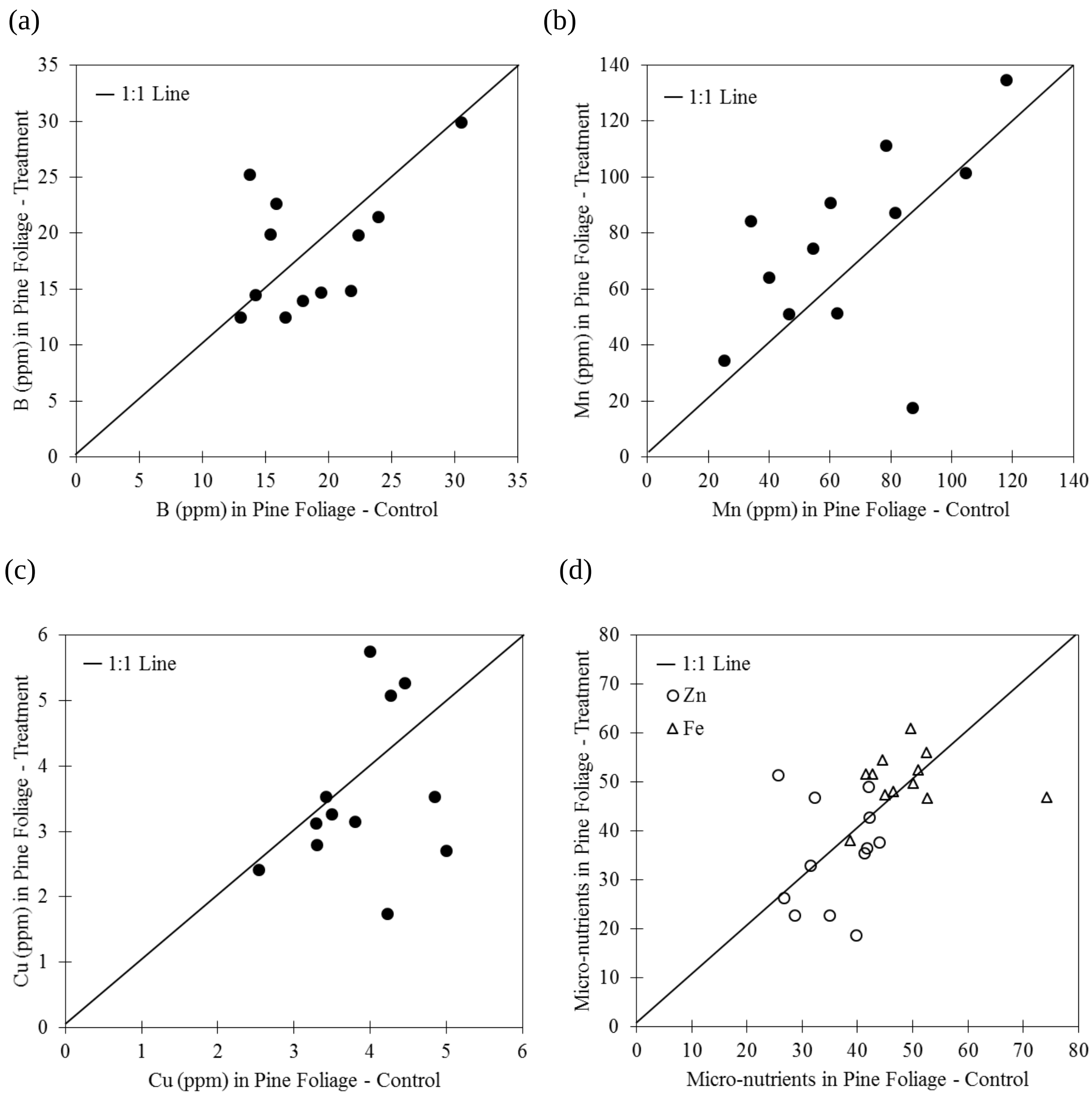


Figure 25: Micro-nutrients boron (a), manganese (b) and copper (c) analyzed from loblolly pine foliage collected from dominant trees in the control and treatment plots at Hofmann Forest, NC. Zinc and iron (d) are also shown together. All values are expressed as parts per million (ppm) and obtained from ground, dry pine needles collected in March 2014.

3.5 Conclusion

The visual assessment and understory competing vegetation (UCV) biomass harvest were verified by the nutritional analysis. When high UCV vegetation levels were observed, the amount of biomass was above average and the corresponding nutrient content was high. The biomass quantity was strongly correlated to the amount of nitrogen (N). The other macro-nutrients, phosphorous (P), potassium (K), magnesium (Mg), calcium (Ca) and sulfur (S) generally followed the same trend, but not for all vegetation types and levels. For instances, the mean P and K content in the UCV, on mineral soil, was greater in four control plots with high levels of broadleaf vegetation than seven control plots with high levels of woody vegetation. This was not the case for high vegetation levels on organic soils. Mean P and K content was higher on 11 woody vegetation controls plots compared to two broadleaf dominated control plots. For the micro-nutrients, as N increased, copper (Cu) and iron (Fe) also increased. Boron (B), zinc (Zn) and manganese (Mn) content varied with different vegetation levels and types. The differences can be attributed to the number of control plots, soil type and species in each.

The UCV nutrient content for the dominant species produced surprising results. Two control plots, one thinned and one unthinned, dominated by *Persea palustris* (swamp bay), had the highest average N content (163.5 kg N ha^{-1}). These two control plots had low (0.9 m^2 m^{-2}) average leaf area index (LAI) and the average UCV was relatively high (12.2 Mg ha^{-1}). Four control plots with a vigorous volunteer *Pinus taeda* (loblolly pine) regrowth, all thinned, had the third greatest average N content (149.2 kg N ha^{-1}). The associated average UCV biomass was also high (13.9 Mg ha^{-1}) and the average pine LAI low (1.0 m^2 m^{-2}). A single control plot, with high competition levels and grass (*Andropogon virginicus* or broomsedge bluestem) vegetation on mineral soil, had 134.2 kg N ha^{-1} in the competing vegetation. The pine LAI was low (1.0 m^2 m^{-2}) and the UCV biomass high (12.2 Mg ha^{-1}). High level woody competing vegetation averaged 109.8 and 111.2 kg N ha^{-1} in mineral ($n = 11$) and organic ($n = 7$) soils, respectively. Thus a single control plot, with grass vegetation, had more N in the vegetation than the average high woody locations. This could be attributed to the different physiological requirements of grasses versus woody vegetation.

While *Eupatorium capillifolium* (dogfennel) was frequently observed as a dominant species, with a modest amount of biomass, the relative nutrient content was low compared to other vegetation. It prefers direct light environments, lowering its importance as a competitor as the canopy matures. However, nutrient content may have been underestimated for the UCV. Miller and Glover (1991) recommend sampling evergreen plants in December or January and deciduous plants in late July, because foliar nutrient content is most stable at these times. All understory vegetation, evergreen and deciduous, was harvested in September and translocation of nutrients could have been occurring. Another improvement to the analysis would be the separation of sampled UCV into species, within growth form, providing a more detailed description of biomass and nutritional values of individual dominant species. This distinction was not made here due to time constraints and large amounts of plant material.

A potential management concern is the vigorous growth of volunteer loblolly pine in thinned stands. In four stands, six to nine years after thinning, a prominent second canopy of loblolly was present. These stands had a high biomass levels and nutrient content. Since the plantations are managed with the intention of promoting loblolly pine survival and growth, volunteer loblolly pines will also respond to the treatments. Herbicides applied to control unwanted vegetation in pine plantations are designed not to harm loblolly. Therefore, volunteer loblolly pine requires another form of control. Fox et al. (2007b) have also brought attention to this problem. If managing a plantation for even-aged harvest with artificial regeneration, special attention should be taken to control this component after thinning.

Loblolly pine canopy biomass and LAI was greater in the unthinned stands, for both treatment and control plots because the thinned stands have not had time to respond to thinning. Therefore, the associated nutrient (macro- and micro-) content in unthinned pine canopies was also greater. More pine leaf biomass will have more nutrition. Within the 17 unthinned stands, the pine canopy biomass was greater in the control plots, but was only one percent different from the treatment plots. P content was greater in the treatment plots than the control plots. All other loblolly pine nutrient contents were greater in the control plots. However, the percent differences in nutrient content between treatment and control plots was less than 15 percent for all nutrients. In the 23 thinned stands, the pine canopy biomass was greater in the control plots but the nutrient content was greater, for all nutrients, in the treatment plots. This could indicate the growing pine canopy is capturing more nutrients than the control in the absence of UCV. The percent difference in values for pine canopy nutrition was less than or equal to 18 percent.

Comparing the UCV vegetation to the loblolly pine canopy, the UCV nutrient content was greater than the pine canopy content in thinned stands. The same is true for unthinned stands for Mg, Ca, Zn, Mn, Fe and Cu. The pine canopies in unthinned stands had greater N and B content than the UCV vegetation. The high nutrient content values are most likely correlated to the high UCV biomass per hectare compared to the pine canopies. Specifically comparing all the nutrients in the UCV versus the pine canopy in the control plots, thinned stands generally had higher UCV nutrient content values. Unthinned stands had greater nutrient content in loblolly canopies for three of seven control plots. The other four favored UCV. Loblolly canopy P was greater than UCV for all seven control plots.

UCV nutrient content correlates to the biomass amount. When high vegetation levels are present, the nutrient content will also be relatively high and the overstory loblolly pine LAI low. UCV is capturing nutrients from the environments. Woody species, such as swamp bay and volunteer loblolly pine are capturing high levels of nutrients. Since these plants persist from year to year, the nutrition will remain in the vegetation. Removing the vegetation will remove the nutrition from the site. Broadleaf and grass species may have high biomass and nutrient contents but they do not persist from year to year. The mortality and decay of the herbaceous vegetation could potentially recycle the nutrition in these plants back into the system.

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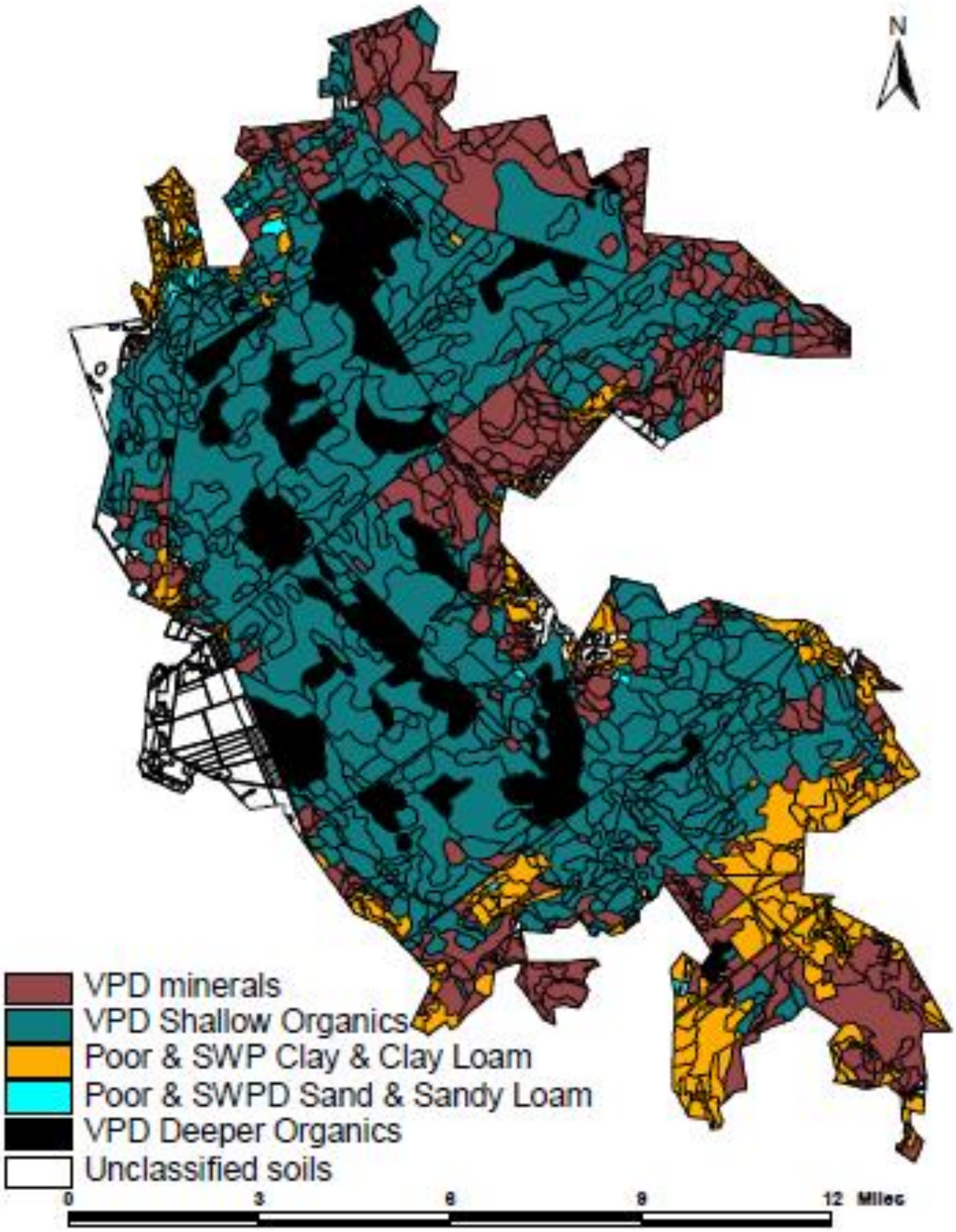
APPENDIX

Appendix A



Soil map for Hofmann Forest, NC (Catts, 2010). VPD refers to very poorly drained. SWP is somewhat poorly drained.

Appendix B

Soil analysis from 2013 for the 40 twin plots at Hofmann Forest, NC (FPC, 2013).

Soil Taxonomy (Order)	**Twin Plot**	**Map Unit (SERIES)***	**Horizon Surface (0 -40 cm)**		**Horizon Subsurface (80 -100 cm)**	**Seasonal Water Table (cm)**
			Textural Class	**Carbon (% average)**	**Textural Class**	
ULTISOLS	1	Pn	loam	6.68	sandy clay loam	75
	2	Pn	loam	7.50	sandy clay loam	>100
	4	Ra	loam	6.80	sandy loam	98
	5	Ra	loam	5.80	sandy clay loam	>100
	6	Ra	loam	5.60	sandy loam	>100
	7	Ra	loam	5.90	sandy loam	>100
	8	Ra	loam	4.80	sandy clay loam	88
	9	Ra	loam	2.62	sandy clay loam	>>100
	10	Ra	loam	6.30	sandy clay loam	>100
	13	Pn	loam	8.55	sandy clay loam	90
	16	Pn	muck sand	6.60	sandy clay loam	60
SPODOSOLS	3	Ct	muck	7.85	fine sand	98
	23	Pn	fine sand	7.85	sand	>100
	24	To	sand	2.76	fine sand	40
	31	To	muck	9.22	fine sand	>100
	34	To	mucky sand	7.01	sand	30
	35	Pn	mucky + litter	7.01	sand	55
	36	Ct	mucky + litter	7.01	sand	60
	40	To	sand	5.49	fine sand	60

INCEPTISOL	29	To	muck loamy sand	9.10	sandy loam	>100
HISTOSOLS	11	Pn	muck + litter	26.92	sandy clay loam	85
	12	Pn	muck + litter	13.76	sandy clay loam	>100
	14	Pn	muck	18.12	sandy clay loam	65
	15	Pn	muck	13.06	sandy clay loam	65
	17	Ct	muck	13.88	loamy sand	>100
	18	Ct	muck	11.26	sandy loam	90
	19	Pn	muck	17.08	sandy clay loam	>100
	20	Pn	muck	13.14	sandy loam	>100
	21	Ct	muck	14.08	sand	>100
	22	Ct	muck	18.73	muck	70
	25	To	muck+ litter	10.48	sand	>100
	26	To	muck	10.51	sand	>100
	27	Ct	muck	11.55	sand	>100
	28	Ct	muck	9.62	sand	>100
	30	To	muck	9.95	sand	50
	32	Ct	muck	13.53	muck	85
	33	Ct	muck	24.34	muck	80
	37	Ct	muck	20.98	loamy sand	90
	38	Ct	muck	10.60	sand	>>100
	39	Ct	muck	11.54	loamy sand	>>100

*Ct – Croatan Muck; Pn — Pantego mucky loam or Pantego loam; Ra — Rains fine sandy loam; To – Torhunta fine sandy loam.

Appendix C

Twin plot age and thinning operations at Hofmann Forest, NC. The twin plots were installed on permanent plots in 2011. Assessments for this study were conducted in 2013.

Twin Plot	Age at Installation (2011)	Age at Thinning	Year of Thinning	Year(s) Since Thinning	Age at Assessment (2013)
1	19	13	2005	8	21
2	2				4
3	16	11	2006	7	18
4	3				5
5	8				10
6	14				16
7	14				16
8	19	11	2003	10	21
9	19	11	2003	10	21
10	5				7
11	13	12	2010	3	15
12	5				7
13	19	12	2004	9	21
14	7				9
15	3				5
16	4				6
17	12	14	2013	0	14
18	17	12	2006	7	19
19	12				14
20	7				9
21	8	10	2013	0	10
22	2				4
23	12	13	2012	1	14
24	5				7
25	10	11	2012	1	12
26	4				6
27	10				12
28	5				7
29	8	9	2012	1	10
30	3				5
31	22	15	2004	9	24
32	11				13
33	2				4
34	17	14	2008	5	19
35	2				4
36	21	17	2007	6	23
37	21	17	2007	6	23
38	4				6
39	10				12
40	21	18	2008	5	23

Appendix D

Fertilization treatments during twin plot installation at Hofmann Forest, NC.

Nutrient	Value	Unit
N	293	kg/ha elemental
P	70	kg/ha elemental
K	100	kg/ha elemental
Ca	198	kg/ha elemental
Mg	43	kg/ha elemental
S	90	kg/ha elemental
B	2	kg/ha elemental
Cu	2	kg/ha elemental
Fe	14	kg/ha elemental
Mn	6	kg/ha elemental
Zn	6	kg/ha elemental
Mo	0.01	kg/ha elemental

Appendix E

Herbicides used at Hofmann Forest, NC in the twin plots to control competing vegetation.

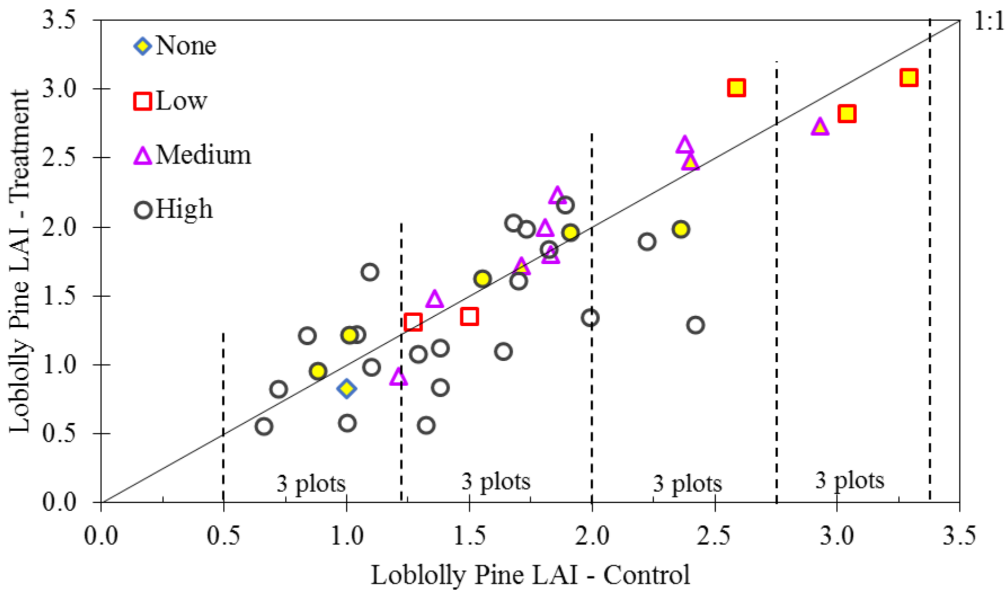
Herbicide	**Active Ingredient**	**Dose (mL/100 L water)**
Garlon XRT	Triclopyr	530
Accord XRT	Glyphosate	3700
SFM 75 (Oust)	Sulfometuron metil	15
MSN 60 (Escort)	Metsufuron Methyl	8
Imazapyr (Arsenal)	Imidazolinona	60
Red River 90 (Surfactant)	Dimethylsiloxane	530

Appendix F

Frequency of the co-dominant vegetation species, by the competing vegetation level, in the control plots at Hofmann Forest, NC in September 2013. The co-dominant species are sorted by most to least common. The total control plots for each dominant species is seen in the last column. One twin plot was absent of vegetation.

	Level of Competition			
Control Co-dominant Species	**Low**	**Medium**	**High**	**Totals**
Acer rubrum	- - -	1	5	**6**
Dichanthelium commutatum	- - -	- - -	4	**4**
Smilax glauca	- - -	1	2	**3**
Ilex coriacea	- - -	- - -	2	**2**
Rubus sp.	1	1	- - -	**2**
Pteridium aquilinum	1	- - -	1	**2**
Aralia spinosa	- - -	1	1	**2**
Cyrilla racemiflora	- - -	1	1	**2**
Lyonia lucida	- - -	- - -	2	**2**
Andropogon virginicus	- - -	1	1	**2**
Erechtites hieraciifolius	- - -	2	- - -	**2**
Eupatorium capillifolium	- - -	- - -	1	**1**
Pinus taeda	- - -	1	- - -	**1**
Persea palustris	- - -	- - -	1	**1**
Arundinaria gigantea	- - -	- - -	1	**1**
Smilax laurifolia	- - -	- - -	1	**1**
Toxicodendron radicans	1	- - -	- - -	**1**
Ilex opaca	- - -	- - -	1	**1**
Solidago sp.	- - -	- - -	1	**1**
Gelsemium sempervirens	1	- - -	- - -	**1**
Vitis rotundifolia	1	- - -	- - -	**1**
Totals	**5**	**9**	**25**	**39**

Appendix G



Loblolly pine leaf area index (LAI) in control versus treatment plots at Hofmann Forest, NC. This figure was used to decide the 12 subsample plots to collect loblolly pine foliage in March 2014. LAI was measured in February 2014. A one to one (1:1) line has been drawn in for easy comparison of LAI values between control and treatment plots. The 40 plots were divided into four groups to cover the spread of LAI values. Three plots were chosen within each of the four groups for a total of 12 plots; seen as the yellow filled shapes. No vegetation is shown as the blue diamonds. Low vegetation levels are red squares, medium levels are purple triangles and grey circles are high vegetation levels.

Appendix H

Descriptive statistics for macro- and micro-nutrient analysis for understory competing vegetation harvested in the control plots at Hofmann Forest, NC in September 2013. Nutritional analysis was conducted by Waters Agricultural Laboratories, Inc. in Camilla, GA.

	Macro-nutrients (kg element ha^{-1})						Micro-nutrients (g element ha^{-1})				
Thinned	**N**	**P**	**K**	**Mg**	**Ca**	**S**	**B**	**Zn**	**Mn**	**Fe**	**Cu**
Mean	86.52	5.33	35.44	10.63	32.81	5.36	99.33	194.58	778.06	263.47	37.68
Standard Error	14.65	1.11	7.53	1.92	5.09	0.76	19.13	31.40	167.10	46.58	6.98
Standard Deviation	58.59	4.42	30.12	7.68	20.36	3.04	76.53	125.58	668.39	186.33	27.93
Sample Variance	3433.03	19.56	907.03	59.06	414.37	9.24	5856.55	15770.41	446747.51	34719.14	780.19
Skewness	1.36	2.04	2.33	1.69	0.60	0.50	1.55	1.22	1.67	1.60	1.41
Minimum	19.19	1.32	7.76	1.87	6.65	1.18	22.19	57.33	239.53	46.19	5.27
Maximum	242.01	19.01	130.83	32.94	71.06	11.72	310.90	517.00	2416.06	800.98	110.94
Sum	1384.32	85.33	567.01	170.04	524.91	85.81	1589.27	3113.24	12449.03	4215.56	602.85
Unthinned											
Mean	78.45	4.72	30.05	10.03	35.05	5.23	87.33	251.07	801.86	285.16	35.68
Standard Error	10.35	0.74	3.72	1.64	6.13	0.79	13.17	53.43	121.39	76.34	5.00
Standard Deviation	49.63	3.55	17.86	7.89	29.38	3.81	63.18	256.24	582.18	366.09	23.96
Sample Variance	2463.42	12.63	319.01	62.21	863.04	14.53	3991.32	65658.56	338928.80	134022.58	574.24
Skewness	0.71	1.13	0.36	1.04	1.21	1.04	0.85	2.79	0.53	3.70	0.72
Minimum	10.53	0.63	3.95	1.00	3.41	0.55	8.66	23.83	44.51	28.88	3.52
Maximum	204.75	13.67	64.20	29.27	119.06	15.82	236.32	1238.29	2143.26	1831.36	81.06
Sum	1804.35	108.49	691.24	230.71	806.09	120.25	2008.64	5774.55	18442.75	6558.62	820.71