ABSTRACT

MASSEY, CAMERON ALTON. Evaluating the Economic Viability of Longleaf Pine Management for Timber Production, Pine Straw Raking, Carbon Credits, Hunting Leases, and Rental Payments (Under the direction of Dr. Rajan Parajuli)

Once historically widespread, the longleaf pine landscape has been replaced substantially by intensive loblolly pine plantation acres and other land uses in the southeastern United States. While longleaf pine has numerous positive ecological and aesthetic attributes, there is a negative connotation of longleaf pine not being an economically profitable option among southern yellow pine species. The main purpose of this study is to evaluate economic viability of longleaf pine plantations by incorporating timber and other potential non-timber revenue options offered by longleaf pine stands. Based on the timber, carbon, and pine straw production data generated from a growth and yield model, we applied the generalized Faustmann model to examine the financial and management implications of growing longleaf pine plantations in the southeastern United States. Along with pole production, we considered pine straw, carbon credits, hunting leases, and rental payments to estimate the land expectation values LEV and optimal rotation ages. Results suggest that when multiple products are monetized from the longleaf pine stands, financial returns are more competitive and the use of available cost share assistance help achieve the highest economic returns. The site index paired with appropriate planting densities can produce varying economic returns and optimal rotation ages under different thinning prescriptions. Results also suggest that pine straw revenues extend the rotation age, whereas carbon benefits shorten the optimal rotation. Reforesting land with longleaf pine plantations could be an economically competitive option for landowners if more potential revenue streams are added to the timber-only management regime.

Evaluating the Economic Viability of Longleaf Pine Management for Timber Production, Pine Straw Raking, Carbon Credits, Hunting Leases, and Rental Payments

by
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DEDICATION

I dedicate this paper to my God, Lord, and Savior Jesus Christ, my future wife Olivia Geen, my family including William Massey, Jennifer Massey, Sheila Massey, My Future Family in Law, and all of those that I have met along the way on this journey.

BIOGRAPHY

Raised in the upstate of South Carolina I grew up with the ability to learn about ecosystems from the pine forests I frequented during deer season and the lakes that kept my attention during the spring spawning season. I began my college career at Tri County Technical College, then Clemson University where I earned my undergraduate degree in Wildlife Biology and Minored in Forest Resource Management. While working construction after graduating Clemson I accepted a position at West Virginia University where I began my Masters of Science in Forestry. After the COVID-19 Pandemic began I transitioned to NC State to finish my Masters. I was also pleased to transition into working in the southern pine industry with International Paper, while finishing my Masters project which encompassed many similar qualities. My goal with finishing this project is to become a registered forester and eventually operate my own consulting firm, where I hope to make a difference in the current forest industry.

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Chapter 1

Introduction

Loblolly pine (*Pinus taeda*) is the primary species for intensive forest plantation as well as natural regeneration throughout the southeastern United States. Other southern yellow pine species besides loblolly pine that compete for planting acres throughout the South include longleaf (*Pinus palustris*), shortleaf (*Pinus echinata*), Choctawhatchee sand pine (*Pinus clausa*), and slash pine (*Pinus elliottii*) (Outcalt, 1993 ; Brockway et al., 2005). Currently, the historically dominant 93 million acres of longleaf pine landscape in 13 southeastern United States have diminished to nearly 4-5 million acres now (Mcintyre et al., 2018 ; Oswalt et al., 2012). Forest management in the form of intense harvesting and the demand of land for agricultural uses were the two primary reasons for the substantial decline in longleaf pine ecosystems. Mills in the early 1900's were breaking production and harvesting records in towns such as Bogalusa, Louisiana, producing over a million board feet of virgin cut pine in one day (Rutkow, 2013 ; Way, 2011). The need for expansion that accompanied these record breaking logging towns was the demand for agricultural lands to feed the expanding Americas (Landers et al., 1995). Today, there are acres being reclaimed for longleaf in the native range (Holmes, 2020). While acres are being planted in longleaf acres, acres of longleaf pine and oak stands are still being lost to regeneration of faster growth species, as well as through urban development (Mcintyre et al., 2018). Similarly, constraints of prescribed fire applications (Way, 2011), the lack of communication that longleaf silviculture has improved, and demand for planting loblolly pine (Susaeta & Gong, 2019) also contributed to the limited longleaf pine acres left in its original territory. Yet, 16 million acres of planted loblolly and slash pine plantations continue to dwindle the existing longleaf acreage throughout the southern United States (Oswalt et al., 2019).

Between 2016 and 2018, private landowners have participated and or completed restoration of over 338,000 acres back into longleaf ecosystems (Susaeta & Gong, 2019). In 2010 the longleaf restoration initiative was established with a goal of nearly 2 million acres being restored, planted, or rehabilitated in the longleaf ecosystem by 2025 (Susaeta & Gong, 2019). The Longleaf Alliance, which was established in 1996 has acted as a network for increasing information availability and advocacy of the species, with an emphasis on outreach of the economic profitability of longleaf as a reforestation option.

In 2011, the Longleaf Alliance reported planting 1.6 million seedlings and assisting in 83,000 acres of prescribed burning across the southeast (Alliance, 2011). Strict management is required of these lands due to their multiple objective management programs. This is required because in cases such as Elgin Air Force Base the resources are available for up to 500,000 citizens around the base and report up to 10,000 active users of the forests (Johnson & Gjerstad, 1998). Experimental forests such as that of Miller Mill Company in Alabama have continued their planting and harvest successfully bringing longleaf products to market from their properties exceeding 200,000 acres (Johnson & Gjerstad, 1998). In 2017, the Longleaf Stewardship Fund was awarded $5.3 million to allocate throughout nine states by the National Fish and Wildlife Foundations NFWF. These grants are estimated to produce $7 million more in match funding. With nearly $13 million allocated from one single source, the interest in longleaf restoration and replanting is expanding.

Utilizing key variables of longleaf growth and yield models such as stem volume production, pine straw production, and carbon sequestration produced an economic baseline to assess overall returns from commercial longleaf pine plantations. With a volumetric timber baseline, other ecosystem products such as wildlife hunting leases and the value added by cost

share programs can be a viable alternative to the other southern pine reforestation options currently available. Longleaf pine is usually not chosen by industrial private forest landowners due to a lack of viable data and models to portray accurate financial return potentials by adequately quantifying the benefits that longleaf stands could potentially produce. The use of the latest growth and yield model developed by Gonzales-Benecke et al. (2015) incorporates a system to estimate pine straw production and carbon sequestration credits to be included in the financial analyses. This is more applicable with plantation pines today because several recent initiatives bring forth new carbon market options for both industrial and non-industrial landowners to participate in forest carbon markets.

The Conservation Reserve Program CRP, implemented by the USDA, reimburses landowners up to 90% of the initial cost of planting longleaf pine on their land. Since 2014, the number of acres allocated to longleaf plantings was 250,000, of which nearly 120,000 were already counted as actively enrolled (Stubs, 2014). The Farm Service Agency FSA as well as the Natural Resource Conservation Service NRCS often offer different funding packages based on landowners' objectives of longleaf pine management. The earlier return on investments allows for a higher rate of return due to the early freeing of capitol. Longleaf can provide these returns from establishments with programs dealing with establishment costs as well as wildlife habitat and ecosystem services.

In order to ensure longleaf to be competitive as a reforestation option, accurate economic return information should be available to landowners that allows them to make educated decisions about choosing longleaf pine to meet their objectives. Some of the new financial return options based on longleaf pine plantations include cost share assistance (Transmittal, 2008). Increased demand for timberland that fosters wildlife for multiple types of recreation in coalition

with increased demand for carbon sequestration (Gren & Zeleke, 2016), improved straw harvesting techniques and an increase in demand for straw and landscape markets (Dickens et al., 2012). Similarly, increased survivability with containerized seedlings (Kara et al., 2017), and improved accuracy in growth and yield modeling (Benecke et al., 2015 ; Dixon, 2013) are also positive aspects of managing longleaf pine plantations.

Further, longleaf pine grows as fast if not faster than other southern pines after the 2-year establishment period with proper spacing and vegetation competition management, which allows the root system to develop (Boyer, 1996 ; Jose et al., 2007). The slow growth out of the grass stage is an invalid representation of the growth of the longleaf stand, and when choosing between species the stand should be assessed between ages 15-30 and should then be considered appropriately (Boyer, 1996). Another factor that seems to be overlooked is the specific gravity and wood properties of longleaf timber, which helps prevent timber damage from natural disasters, wildfire, insects, and disease that wreak havoc on lesser dense woody pines (Jose et al., 2007). The grades of pine logs are based on the density of the wood, and with the longleaf having the densest, it produces the highest quality products such as poles and beautifully dense saw-timber (Clark & McAlister, 1998).

The main purpose of this study is to evaluate the economic profitability of longleaf pine plantations by accounting for all potential timber and non-timber revenue streams. Specifically, the non-timber benefits are coupled with timber production to assess a maximum Land Expectation Value LEV that longleaf pine stands can provide in order to compete with other viable tree crops. This study will showcase the use of multiple revenue streams not available to every pine plantation species, most notably the CRP rental and cost share payments, as well as the premium straw prices that come as a byproduct of growing a longleaf plantation. With

multiple benefits stacked, the optimal rotation age should be representative of which product has more effect on maximizing value with the inclusion of other values from multiple products coming from the stand.

In addition, as a resource for extension, this thesis will mention of four different programs in which CRP allocates annual funds to assist landowners as a revenue option on their lands via less erodible agricultural practices. The accurate projection of returns associated with a lower establishment costs will be more attractive for landowners interested in longleaf regeneration. The growth and yield model was run and data exported to excel using features of the Gonzales-Bencke model that included rotation age, thinning's, target and residual basal area, prescribed burning, straw production, timber production, and carbon sequestration. Utilizing the generalized Faustmann model for financial analysis we obtained the optimal rotation age and LEV for each combination of products coming from a longleaf stand (Chang, 1998).

The findings of this study suggest that economically competitive returns are available with planting longleaf pine, reigniting hopes that the once dwindling range of longleaf can increase its landscape across the southeastern range again. The choice of planted longleaf proves to be competitive in lower and higher site quality tracts, allowing landowners with site indices typical of a family farm or timberland to have options other than managing for loblolly timber. The results also suggest that the stacking of revenue streams produced by a longleaf plantation will not only yield higher financial returns but also alter forest management strategies. For example, the cost and spacing associated with biological responses of longleaf at a higher planting density, such as 605 trees per acre, can limit returns unless planting conditions are suitable for this density. Also, lower site quality land can shorten the optimal rotation age.

Furthermore, basal area prescriptions will affect the volume of timber growth in regards to what the target and residual basal areas are set, triggering the time of thinning operations. Longleaf products associated with CRP rental payments and cost share programs will outcompete product combinations that accrue interest on full establishment costs at the beginning of the forest stand planting. The addition of revenues such as pine straw and carbon sequestration payments added to a timber baseline increases the stand rotation age to maximize benefits from these products. The analysis of the site index factor shows the competitive advantage landowners with a certain quality of land will have in planting longleaf versus loblolly or slash pine.

The rest of the thesis is structured as follows. The next section begins with a historic literature review that shows how longleaf pine helped build the southeastern states in North America (Hickman, 2009). Lumbering and production of industrial goods in the form of naval stores explain why the decimation of longleaf pine stands occurred (Outland, 1996). The historical section follows a comprehensive literature review that led to many questions as to which prescriptions can increase landowner returns, thus increasing the longleaf acres scattered through the 13 southern states in the longleaf's native range (Oswalt et al., 2012).

A review of economic literature that utilized the generalized Faustman model to determine optimal rotation age, maximum returns, and decision models to achieve the highest returns led to the questions of which factors in longleaf plantation forestry most affect the returns. In order to answer this question an experiment was developed to understand the outcome of every plausible scenario a landowner interested in longleaf pine could face. A multitude of results demonstrate common trends that correlate with the findings of the generalized Faustmann model (Chang, 1998).

The methods are presented next and delineate each aspect of the model associated with this project, why we chose the generalized Faustmann formula, and how we analyzed combinations of timber and non-timber benefits. The results section presents the primary findings of this study. We concluded with a discussion of the results and potential recommendations for policy makers and landowners to bring the financial profitability of longleaf pine to their full attention.

Chapter 2

Historic Accounts of Longleaf Pine Stands

As manufacturing industries progressed across America with iron production occurring in the clay furnaces in the steel states around West Virginia, coal production in states such as Kentucky, and lumbering in the Northeastern states. Naval stores production took its place in the agroindustry of the South to help push the United States into the list of world powers. As colonization progressed, the number of slaves brought into the colonies to assist progress increased. This included the naval store industry of North Carolina (Outland, 1996). The historic range of longleaf stretched from Norfolk, Virginia to the pine savannas of Texas (Brockway et al., 2005). An inability to reproduce itself naturally was one of the major downfalls to the natural range of longleaf pine.

The deforestation of longleaf pine stands began as early as the mid-1600s. Timbering was dependent upon accessible timber and access to the waterfront. Rivers were used to float down the logs and naval store goods. The commercial deforestation was tame until steam technology made its appearance in the mid to late 1800's. This laid the foundation to maximize logging production, which peaked between 1870 and 1930 (Frost, 1993). The water powered sawmill had emerged in many of the longleaf states but was limited by volume transported to the mills (Hickman, 2009). Trains allowed transport of naval stores and materials cut while the steam powered skidder dwindled the historic longleaf inventory. With several new forest industry technologies, lack of proper management, and a demand for naval store goods, the longleaf pine range declined from the original 92 million stand acres to less than 3% of historic longleaf stands left today (Frost, 2007).

The transition from Native American societies to English societies and their slaves led to the idea of fire exclusion. The settlers thought this was better for the land. Fire exclusion accompanied with Eurasian Boar browse in competition with livestock browse, and the lack of regeneration management were some of the primary causes of the shrinking longleaf ecosystem. This was common into the early 20th century when the US Forest Service, state agencies, and the Bureau of Biological Studies, today known as the US Fish and Wildlife Service (USFWS), implanted groups such as the Dixie Crusaders to push against the use of fire as a management tool (Van Lear et al., 2005). By 1930, most of the longleaf stands across the south had been decimated other than those protected from the returns of hunting plantation boundary lines (Van Lear et al., 2005). The use of pine as a crop did not take an industrial agricultural plantation form until the late 1800s to the end of World War II era (Frost, 1993). Even with the arrival of private and federal pine plantations, much of these were of loblolly and not longleaf stands.

Reports of this 100-year Naval Store industry exponentially rose in the 19th century in comparison to the few dozen barrels produced by Captain John Smith at Jamestown. North Carolina led the industry in the 1847 De Bow's report, producing 800,000 barrels of turpentine out of pine. The industry grew even more in North Carolina producing almost 97 percent of the industry's American export in the late 1800s totaling an estimate of $1.7 to $2 million in exports (nearly $67,000,000 today), excluding all the other states partaking in the industry (Outland, 1996). This elevated naval stores to the Southeast's third largest export behind cotton and tobacco.

The industry was overtaking the coast from 1730 when heavier production began, to its industrial birth in the 19th century. Nearing the middle to end of the 1800s, a staggering economic estimation of nearly $5-$6 million ($200,714,634 today) worth of naval store products

were being produced in the state annually (Outland, 1996). To this day the port of Morehead (transitioned from the earlier settlements from New Bern to the port of Moorhead today) remains one of two primary ports on the North Carolina coast. These ports were responsible for establishment of NC as the export capitol for naval store products. Longleaf in NC yielded the best resin harvest but was exhausted through development of the coastal towns and ports. The longleaf was found, even by limited forestry educated producers, that the pine grew the best in harsh conditions and sandy soil, which produced some of the largest stands in the middle of North Carolina. Production was occurring as far north as Nash County, adjacent to Wake County in North Carolina, to be shipped down river to the ports (Outland, 1996).

Longleaf had been exploited to further the economic standing of southern states such as North Carolina. Supply chain and logistics, supply and demand, and resource capabilities continue to drive markets today just as they did back then. With more people residing on planet Earth than ever before, foresters and natural resource managers are blessed to be tasked to figure out the solutions of high demand and finite supply. Logistics have played a key role from sending naval store goods down the Neuse River including harvest of resin to collect turpentine longleaf across the southeast. Supply and demand of longleaf are no longer of turpentine, pitch, and tar but of wood and forest products such as pine straw, utility poles, and carbon credits. With as few as three million acres left of original longleaf stands, reforesting and ecosystem restoration needs to occur before products are harvested (Johnson & Gjerstad, 1998).

The study of historic disturbance is required to ensure the longleaf ecosystems are planted and managed in ecosystems they are adapted for (Van Lear et al., 2005). After the depression era, forest management was implemented across the longleaf landscape. Fire and habitat management became more prevalent through the 1930s to the 1950s being backed by the

pulp and paper industry (Johnson & Gjerstad, 1998). The requirement of shorter rotational species proved to be too fast of an industry for longleaf to compete with. Private landowners prepped and planted their lands in the shorter rotational crops, and because of loblolly's competitive nature, abandoned neighboring lands were naturally regenerated with species such as loblolly and Tulip-poplar (*Liriodendron tulipefera*) (Johnson & Gjerstad, 1998). Many acres have been converted to slash pine, loblolly pine, or mixed poplar hardwood stands since the felling of the natural range of old growth longleaf pine stands.

Although the economic demand of forest products is a driver for the development of restoring longleaf in the United States, not all individuals are bound by economic progress. One case in point is Herbert Stoddard, a renowned wildlife biologist who found himself in the pine barrens of the Florida and Georgia line. He found a southern heritage and a mosaic of an ecosystem, rather than what most people would consider to be a simple commodity (Way, 2011). In the early 1920s, Stoddard made his way into the Red Hills. He was working for the federal government to further "conservation" policy stretching from woodlands in Thomasville, Georgia to Tallahassee, Florida (Way, 2011). In his time working for the Bureau of Biological Survey, currently known as the US Fish and Wildlife Service, he found himself among many plantation owners who were unable to keep their Bobwhite quail numbers from diminishing. After careful study of the landscape and game that inhabited it, Stoddard discovered evidence of the ecosystem needing management.

This was the opposite of federal opinion at the time. Conservation "experts" were working with the bureau to ensure that the southern practice of burning private land was eradicated. Stoddard saw not only a management practice but a necessity to produce a thriving longleaf ecosystem. Continual disturbance via prescribed fire and timber management proved not

only to be healthy for the fire adapted quail, but also allowed regeneration of the longleaf. While completing the federal tasks required of him, he became a student of the land. He realized that policy creators do not always have the knowledge that works in the field. In fact, most of his work was completed as a private citizen. He would work with the quail plantations that surrounded his federal jurisdiction (Way, 2011). These principles of longleaf management proved to be the foundation that biologists and foresters utilize today to ensure that forest ecosystems are protected from further mismanagement.

With the renewed interest in the species after a 200-year decline, longleaf candles are beginning to flicker once again with multiple cooperatives associated with longleaf. With federal land being managed on military bases such as Elgin Air Force base, Fort Bragg, Camp Lejune, and Fort Stewart, an estimated 4.7 million acres of longleaf have been under intense federal forest management (Brockway et al., 2005). The rest of the estimated 1-4 million acres lie on private, corporate, and state lands. Strict management is required of these lands due to their multiple objective management programs.

Cost share programs through federal agencies such as the Natural Resource Conservation Service NRCS, the CRP, and privately established experimental forests. The Longleaf Alliance established in 1996, has acted as a network for increasing information availability and advocacy of the species. These agencies and initiatives have been taking the charge in outreach activities on the economic profitability of longleaf, a viable reforestation option leading last year's longleaf reforestation efforts at replanting 138,223 acres in longleaf, prescribed burning longleaf stands over 1.4 million acres, and by establishing almost 35,000 acres in acquisition and easements for longleaf (Holmes, 2020).

Longleaf has always found itself in the coexistence of the Red Cockaded Woodpecker (*Leuconotopicus borealis*) due to co-evolutionary qualities. Mature trees with high resin flow allow for the woodpecker to nest within the tree while providing natural barriers to predators desiring cavity contents (Kaiser et al., 2020). Thus programs such as the Safe Harbor Program in North Carolina as well as wildlife habitat incentives programs assist landowners in the cost of managing portions of their timber stands for wildlife habitat purposes (Smith et al., 2018 ; Sunday, 2012). The Forest Development Program FDP, similar to wildlife habitat programs also classify longleaf as a necessary species for further restoration and development. The FDP subsidized species such as longleaf to receive a 60% cost share of establishment and forestry practices that occur to regenerate longleaf and other "high priority" species in the state of North Carolina (Chizmar et al., 2021), showing localized interest dependent upon suitable location and funding to increase participation in the species regeneration.

Chapter 3

Literature Review

Longleaf pine for timber production

Multiple studies have been conducted to compare the biologic qualities of longleaf to other plantation pine species. Longleaf is considered a slower growth species due to its long tap root period to develop its root system and its natural stands longer growth period (Jose et al., 2007). Several studies have reported higher success rates with proper vegetation control, planting density, and site quality that showed very rapid root growth causing shorter grass stages for the young longleaf (Boyer, 1988 ; Kara et al., 2017 ; Jose et al., 2007).

Longleaf has an extreme resistance to fire in the seedling stage as well as throughout the rest of its lifecycle (Landers et al., 1995). Being a slower growth species due to a longer seedling stage is frowned upon when trying to maximize economic gain. Under proper conditions a shorter rotational species can produce volume quicker. However, longleaf can derive a value by producing a denser wood, which is a more valuable product.

Boyer's study showed that longleaf's grass stages (first years after planting) are shortened, increasing competitiveness when applied to the correct site, planting density, and the utilization of containerized seedlings. The first year after planting showed a 25% higher survival rate than bare root seedlings and increased to 30% survivability by the end of year 3 (Boyer, 1988). Different types of forest harvests bring different results in how long it takes for longleaf to exit the grass stage when not outcompeted by the parental over story (Jose et al., 2007). This grass stage can be shortened with an even aged cut, appropriate vegetation competition control, and planting at appropriate densities, which were shown to be between 436 and 605 trees per acre depending on site quality (Larson, 2002).

On average, longleaf can produce up to 80% classified utility poles. This is due to a higher specific gravity which produces more weight in the tree, while most other southern yellow pines produce a much smaller portion of pole class timber (Landers et al., 1995). This higher percentage of pole class timber produced from longleaf plantations is the same reason the species is correlated to less hurricane damage in that it is more dense timber (Johnsen et al., 2009). Pole class timber in southern yellow pine brings the most revenue off the stump in comparison to the other grade logs. One class 1 pole from the stump can be worth from $48 to $875 dollars depending on its diameter breast height DBH and other attributes, such as tapper and wane once processed, treated, and delivered to market (Quicke & Meldahl, 1992). The stumpage price is more representative in dollars per ton to be paid to the land owner, which in 2021, was reported at $42.51/ton (TimberMart-South, 2021).

The species is considered a risk averse choice to investors due to ability to withstand an excess of issues foresters are dealing with in the field. The next most inherent risk of planting southern yellow pine is wind break. With a changing climate, weather patterns are becoming more unpredictable, and insurance is offered through mature longleaf, one ability that longleaf has is tap root to reach a soil depth of up to 12 feet. This permits access too hard to reach nutrients and stability in less ideal planting sites (Boyer, 1990). A study in Mississippi showed that stands susceptibility to wind throw in southern yellow pine species was the lowest in longleaf stands, compared to other southern yellow pine species (Johnsen et al., 2009).

Another representation in yield data today states that longleaf is biologically outcompeted by both loblolly and slash pine. Most of the literature involved with longleaf tends to maximize conservation at whatever cost necessary. The ability of longleaf to grow at competitive rates has been refuted by several studies that showed the normal management choice of longleaf pine

prepared sites comparing longleaf to slash and loblolly planted side by side (Outcalt, 1993 ; Boyer, 1996).

For instance, a site planted in the sand hills of Georgia and South Carolina showed that longleaf had up to an 11 feet height advantage by the age of 28 (Outcalt, 1993). The longleaf at age 15 was also growing as fast as the sand pine and was deemed an acceptable alternative species (Outcalt, 1993).

Another example of a prepared and planted site in Mississippi showed that longleaf catalyzes its growth rate after the sapling stage. At age 10, longleaf saplings were surpassed by loblolly pine with an 8 to 9 feet height advantage. By age 17 the longleaf surpassed the neighboring loblolly and was competing to surpass the slash (Boyer, 1997). Diameter is the other aspect in which slower growth is assumed in comparing longleaf to other southern yellow pines. The specific gravity of timber is closely related to the strength of dimension lumber and poles (South, 2005). The comparison of value of diameter in relation to a difference in species should account for the quality and volume of quality that longleaf produces in longer rotation to that of which produces volume quicker (South, 2005).

Longleaf is also very adaptable when it comes to pests and diseases. Some of the more specific ailments that have proven to decimate loblolly and slash stands are fusiform rust, Annosus root rot, pitch canker, southern pine beetle, and tip moth. A study conducted using FIA data showed that the higher probability of disease and beetle outbreaks in shorter rotational species in comparison makes longleaf financially competitive long term; loblolly was financially superior in producing fiber quicker but was less competitive as stand damage probability increased (Moser et al., 2003). Planting longleaf is a long-term investment but can pay off by reducing a risk of losing future value of their investments (Landers et al., 1995).

Limited research and outreach to communicate the economic viability of longleaf pine plantations have restricted the wider consideration of longleaf pine as a viable reforestation option (Rutkow, 2013 ; Susaeta & Gong, 2019). To obtain the most accurate land expectation value of the stand, it is necessary to account the production of timber benefits and non-timber benefits. This includes revenues such as stumpage price, and goods and services such as habitat, carbon benefits, and pine straw projected into the future at the current discount rate.

The desire to produce non-timber benefits is becoming increasingly relevant with a viable return option. This creates the need for models such as the reservation price strategy (Gong et al., 2005). The results of an adaptive harvest strategy can maximize the net present value of a stand of longleaf versus loblolly (Susaeta & Gong, 2019). Timber prices will always be uncertain to an extent as a market commodity. Determining the appropriate time to sell timber products is the traditional question that drives landowners to make decisions on their land. However, if the timber prices are lower, landowners need other viable options of income to validate allocating their capital in their timber properties. Putting a dollar value on non-timber ecosystem goods and services is a viable option.

Economics of longleaf pine

The Faustmann Model developed by Martin Faustmann, a German forester in 1849, is the most common application in financial analyses in forestry (Faustmann, 1849). In many ways the Hartman Model (1976) is similar to the generalized Faustmann model in that the model includes payments from annual or periodic incomes from non-timber goods and services in addition to the value of the timber (Hartman, 1976). The generalized Faustmann model was created to value land with standing timber, including stumpage price at a certain age, volume of a stand at a certain age, regeneration cost, and the interest rate as the first land expectation value LEV1. This

model also includes the uncertainty of future land values LEV2. Stochastic variables able to be accounted for in the generalized Faustmann model includes land productivities, market fluctuations, and any uncertainty the future may hold affecting returns. This formula has been utilized to value land and timber from when it was created similarly to present day as it is still taught in forest economics. The issue with the traditional formula is that this equation assumes that the variables such as timber prices and interest rate above are set constant throughout the future rotations, whereas the generalized model includes the effect of these values for resulting returns and optimal rotations through sensitivity analysis of LEV2 (Chang, 1998).

However, timber prices change with the cost of performing business. Chang (1983 ; 1984 ; 1998) has expanded upon the Faustmann model due to realization that rotation age is subject to change every rotation. The stochasticity of each of the variables were examined to ensure that accuracy of the LEV. Chang (1998) developed a generalized Faustmann model which allows for the determination of optimal rotation age for every stand grown. Local market data allows one to determine the most accurate LEV with year to harvest for every forest stand that will be analyzed (Chang, 1998).

Several case studies have evaluated the financial implications of managing southern yellow pine plantations by employing the Faustmann model. Mills and Stiff (2008) compared the return rates for stands with and without pine straw harvests using ForSIGHT resources, compared the returns of longleaf using growth and yield simulators FORsim longleaf growth stimulator, and LobDSS for Loblolly. Land expectation values were set at real interest rates of 5 and 7 percent. All scenarios analyzed returns and showed that adding pine straw increases the revenue of longleaf plantings. Loblolly returns outcompeted all longleaf scenarios other than case four in which the best management scenario of longleaf surpassed loblolly’s LEV by 2.6%

(Mills & Stiff, 2008). The results of the case study showed that positive returns did not occur until age 23 for either species and most gain occurs at the end of the rotation where most of the wood is harvested. If longleaf can reach a shorter grass stage or shorten its rotation length via fertilizations, then the accompaniment of pine straw could produce more profitable returns. Although loblolly LEV outcompeted longleaf for the majority of these analyses, one factor to be considered is establishment cost. With federal, state, and private cost share available the establishment of longleaf can be planted at a fraction of the price, making the similarly comparative returns much more attractive for longleaf (Mills & Stiff, 2008).

One particular case study in Thomas County, Georgia shows the value of the hunting leases in association with plantations in comparison to the revenue produced (Kush et al., 2005), which factors into many land decision variables for southern landowners. In fact, the net worth of the non-timber activities resulted in two alternative management plans depending on the price of timber. They estimated that if necessary, timber will be allowed to grow and the family property can still earn a profit off hunting leases worth up to $10/acre/year the timber is not cut. The longleaf inventory on site was also first estimated at $1067/acre and over the course of 33 years, was worth nearly $1700/acre. This proved to be a reserve capitol allowing the profitability of hunting leases associated with the plantation to produce primary returns, with reserve capital available (Kush et al., 2005).

Another case study via the Georgia Forestry Commission shows that in comparison to traditional timber products alone the NPV can be converted from -$59/acre to $205/acre with the addition of hunting lease and pine straw revenues (Sunday, 2012). The high site quality produced positive returns of $564 under their management assumptions. The medium site quality produced

an NPV of $264/acre. The low site quality produced a negative NPV of -$59/acre (Sunday, 2012).

Haung (2009) showed that the profitability of managing for quail and timber allows for multiple revenue options to landowners who might have less than ideal site quality for timber production. The study showed that landowners could still make percentage returns off lower quality timber with an additional revenue if co-managed for Bobwhite quail. If both hunting lease and timber tradeoff are optimally managed, then you could experience up to a 807% increase in economic gains (Huang, 2009). Similarly, Davis et al. (2017) found that the addition of hunting leases carries a wide range of profitability from nearly no management, allowing hunters to purchase leases for the purpose of covering property tax up to wildlife production via a managed forest system that offers more competitive returns than some of the wood products produced (Davis et al., 2017).

Stainback and Alavalapati (2004) showed a viable option that lies with the multiple management objectives of silvopasture. This style of ranching includes the production of timber, cows whether for beef or dairy products, and straw raking (Stainback & Alavalapati, 2004). The results of this study showed that traditional forestry can be more optimal if including carbon credits with a ranching style of forestry, to include agricultural and forestry practices. The extension of the rotation ages allowed for this payment as well as the development of mature timber which brought forth value in wood products and wildlife habitat, creating an economically viable option for landowners interested restoring longleaf.

Optimal Longleaf Silviculture

The two types of longleaf management are uneven aged and even aged management, sometimes the difference between naturally occurring and planted longleaf stands. Natural

regeneration is variable in projecting what the forest will produce over the span of a single rotation. The ideal alternative for landowners who want to invest little capital into their longleaf stands can produce quality timber and products on a medium site with a quality of site index 70-80 feet. A seed tree cut will allow natural regeneration to occur on the forest floor of up to 4000 seeds per acre, and 2-4 cords produced periodically every 5 years via a seven-step process outlined by William Boyer with the US Forest Service (Boyer, 1979).

Despite cost effectiveness, not every site is suited for this option. Variables applicable today include the effects of island biogeography in the sense that timber land can be managed completely different from one side of the tax parcel boundary line to the other. One major difference is whether land is fire inclusive or exclusive. If no fire ever reaches the floor, longleaf seeds will not be released from their cones to bare mineral soil. If fire is too frequent then the risk of burning the seed crop arises. Either one suppresses the next generation of longleaf from taking root (Jose et al., 2007). Fire is just one of multiple variables to prevent optimal stand rotation management of longleaf and brings forth the more suitable option of plantation management, an implication of the need for timber, and financial projection.

Silvicultural prescriptions are dependent upon geographic location, landowner objectives, and site quality. Another factor is planting site locations which primarily occur in the Piedmont, coastal plains, and the coast of southeastern United States. If the landowners desire a more cost efficient approach to growing their timber, then natural regeneration is a good silviculture option. This option has proven to be difficult for successful seedling growth and survivability, extending rotations. This leads to opposition such as inadequate seed crops from too few seed trees, unplanned fires, wildlife predation, and insects and infections (Jose et al., 2007).

Most of these issues can be remedied with appropriate site preparation including prescribed fire one year before the seed crop fall (Miller et al. 2006). If the under and mid-stories of the existing longleaf stand are in competition with woody species such as hardwoods, then mechanical removal and herbicide application may also be required to ensure a proper seedbed is ready for the parent tree's seed crop.

The next viable option would be artificial regeneration in the form of direct seeding. The plantings need to be done with seeds from similar zones. Longleaf has five effective seed zones for geographic locations that should have seeds selected from similar zones. Once seeds have been selected, the seeds have to be carefully stored and transported to the planting site.

Naturally, if attempting this regeneration type, the site quality should be adequate for longleaf usually meaning not too wet, not too high of a slope, and with mineral soil exposed for the seeds. If shrubs and grass competition, is likely then prescribed fire should be examined and if woody vegetation is likely, then mechanical and chemical competition control should be considered. Seedling rates should be considered at no less than 12,995 treated seeds per acre for broadcasting and 6,800 if row planting. Spot seeding should contain no more than 6 seeds per spot. A small amount of soil to cover the seeds has also shown higher germination rates between 4mm and 6mm of soil covering. Lastly, if seed stocking is greater than 50% then a longleaf tree stand should grow accordingly (Miller et al. 2006).

The two primary types of seedlings used in longleaf plantings are bare root and containerized seedlings. If using bare root seedlings the site should be around 90 to 95 pure seedlings with a germination rate of 75 percent with appropriate site conditions (Miller et al., 2006). Water and fertilizer are required for this method in proper amounts with proper pH of 5-6

similar to that of the soil. Bare root nursery seedlings should be grown at a basal area density of between 108 and 160.

Containerized seedlings are the next viable planting option. Longleaf tends to germinate during the cooler months before winter with an average temperature of 70 degrees Fahrenheit. Fertilizer should be applied according to the phase of the seedling. Fertilizers used should be balanced in equal parts containing Nitrogen, Phosphorus, and Potassium. When considering regeneration methods via seed or seedling cost is one of the primary factors in decision making. Although containerized seedlings may be the most efficient production option they can only be used if they are affordable. Site preparation is key for seed success; if the site has been actively managed then the input for planting could require as little as a prescribed burn but improperly prepared sites could result in low germination, survival, and growth advancement (Boyer, 1988; Cohen & Walker, 2006; Knapp et al., 2006; Miller et al., 2006).

The method of cut and plant proves to be more costly considering infinite rotations of stands due to the destruction of advanced regeneration (Miller et al., 2006). The seed tree method involves removing much of the mature over story. The goal of this type of harvest is to ensure that enough advanced longleaf saplings are left on site. Generally, 9 to 12 healthy parent trees per acre will ensure future seed crops and even distribution throughout the site. This is considered even age management because once regeneration has established itself the residual trees from the prior rotation will be removed. This method does not always fit optimization models for forest products because the output of longleaf seed trees is not always high enough to produce competitive regeneration.

Shelter wood methods remove less over story than seed tree reproduction methods. The amount of parent trees on site allow regeneration to establish itself under the protection of the

residual over story. Typically 20-25 parent trees per acre will produce sufficient seed to establish and distribute across the landscape (Miller et al., 2006). This method allows for genetic selection by leaving the dominant trees of the stand which tend to be larger, more competitive seed producers, with higher live crown ratios. The uniform shelter wood method appears to be most effective utilizing two or three cuts including the preparatory cut, the seed cut, and the removal cut, the difference between the two methodologies being the seed cut. The diversity of the shelter wood method allows for regeneration of longleaf to be tailored to each manager's objective while keeping producing future stands of longleaf (Miller et al. 2006).

Uneven aged silviculture has increasingly gained interest among managers as well. The premise of uneven aged management includes several longleaf stands within one property boundary. This allows for the development of larger old growth longleaf, always having a forest canopy, and protecting the natural understory (Miller et al., 2006). Methods include group and single tree selection.

Group selection allows for higher production of seedlings in a canopy gap created with the selection of a group of trees within the stand, mimicking a natural disturbance such as an infestation or a lightning strike. Each group selected creates a variety of gaps of every shape and size less than an acre to nearly two acres. Poor quality trees should be the focus of the removal to allow for better genetically qualified trees to reproduce. Single tree selection allows for selection of poor trees to be removed similar to that of group selection but only removing one tree at time. This results in many entries over a longer period of time to ultimately produce the same result as group selection but at a higher cost, which is more cost inefficient for those who want to manage an uneven aged longleaf stand (Miller et al., 2006).

Fire is an intricate part of longleaf silviculture in that it is utilized before longleaf is planted, is prescribed cyclically, and has been a natural part of the ecosystem due to the species' years of adaptation. Fire is utilized after a harvest of trees to expose mineral soil which is key to site preparation for longleaf seed and seedlings (Miller et al., 2006). Pre-European settlement showed the effects of prescribed fire used by Native Americans on the stand, excluding hardwood and vegetation competition from entering the mature longleaf stands (Frost, 1993). Cutover lands of longleaf that are growing sub-optimal second growth timber benefit from competition removal via prescribed burning and the nutrients released back onto the site (Frost, 2007). To complete the rotations cycle the use of fire allows for an aesthetic understory that is pleasing to recreationists for old stands left to grow and to industry personnel who have to enter the stand for wood product removal.

Optimal Longleaf Management

Chang in multiple studies has factored in the need for accurate portrayal of the optimal rotation year (Chang, 1983 ; Chang, 1984 ; Chang, 1998). Chang (1998) developed the generalized Faustmann model to take into account the variance of future land value based on the fact that the timber, site quality, and prices are ever changing. Others have used this modified version of the Faustmann model in determining their optimal rotation age for many pine plantation species.

Haung and Kronard (2006) applied this to loblolly plantations assessing the benefits provided from carbon sequestration. Parajuli and Chang (2012) applied this method in the quantification of uneven aged management of loblolly incorporating benefits from carbon sequestration as well. A recent study also applied this model to longleaf plantations in accordance with multiple benefits provided as byproducts of longleaf (Paudel & Dwivedi, 2021).

Chang and Gadow (2010) advanced the stochasticity variables of the model by additional accounting for future values of stumpage, annual income, interest rates, residual growing stock, and LEV of uneven aged stands applied to loblolly and slash pine stands. Deciding which of these values have the most effect on LEV was evaluated by the most efficient use of the Markov Decision Model. Using this model allows one to choose which of the variables to evaluate in order to determine the most accurate future land projection (Buongiorno, 2001). In order to do this an economic model had to be chosen to best fit this project. A multiple revenue model for longleaf was developed by Suseata and Gong (2019). Stacking benefits generates higher returns, therefore, most agree that optimization of timberland must include management for more than one revenue source.

Multiple studies have utilized the generalized Faustmann model to determine the optimal rotation age. A study of uneven management of pine plantations grown with carbon sequestration payments was conducted by Parajuli and Chang (2012). Another uneven aged management study quantified application of this model and added several other future values to find the optimal rotation age to slash and loblolly pine stands for optimal timber management under natural and plantation qualification (Chang & Gadow, 2010). Another study utilized the model to further the accuracy by adding stochasticity assumptions of probabilistic future timber prices in with the Markov Decision Model (Buongiorno, 2001). The generalized Faustmann model developed by Chang (1998) is the basis of the economic model for this project.

The development of the generalized Faustmann model provides flexibility in stagnant assumptions such as constant timber prices, stand volumes, and regeneration costs from rotation to rotation. The addition of the future value of the next stand added by LEV2 provided in the generalized Faustmann model adds a dynamic tool to a previously reliable method for

calculating LEV. Previous assumptions in economic modeling show that timber prices will increase by a percentage each year.

In correlation, management and regeneration costs will increase marginally to the increased price in timber (Chang, 1998). With the addition of the future value of the future stands, optimal rotation age, and LEV are no longer bound to stagnant assumptions that are represented above. This will be apparent in the model associated with this project in that each product scenario will have its own optimal rotation age.

However, every quarterly report on stumpage price proves this to be untrue. Harvest prices change with the cost of performing business. Rotations produced on the same piece of land are unlikely to ever produce the same amount of volume. With accuracy of optimal management and yield projections comes change as the evolution of the Faustmann Model to the generalized Faustmann model, the LEV no longer stays the same. This formula allows for the study of future stands based on projected data via growth and yield or physically collected stand data. The importance of the model allows for the determination of optimal rotation age for every stand grown. Analysis after finding the LEV will help determine what year harvest assuming the objective is to produce the most revenue. The model allows for change in that every year the cost of stumpage will change as well as interest rates. Local market data wherever you are working will allow one to determine the most accurate LEV allowing you to determine the best year to harvest for every forest stand that will be analyzed (Chang, 1998).

Many studies have represented several forms of LEV to try and find the optimal financial management regime for longleaf. A recent study from Georgia found that optimal longleaf management occurs with pine straw and a multitude of cost share programs that are

currently available to non-industrial forest landowners (Email Communication, Yanshu Li, March 2021).

Similarly, Roise et al. (1999) found that stacking benefits of pine straw and wildlife habitat in the form of long-term rotation management produced optimal returns when considering the negative effect of lack of revenue when managing for protected wildlife species by adding that of a profitable by-product, pine straw. Wildlife habitat incentives programs (WHIP), case studies have shown positive return of 12.66% and CRP returns of 38.31% (Sunday, 2012). Contracts such as the CP3A contract allow $100/acre to sign up bonuses and establishment cost share of up to 90% but do not allow pine straw harvest during the contract (Sunday, 2012).

In order to maximize benefit, the rotation age must be determined to maximize the land expectation value LEV of timber products and by products of longleaf pine. Suseata and Gong (2019) utilized an adaptive harvest strategy model to determine the most optimal year of harvesting based on the minimum and maximum expectation values that are projected to be comparative of their timber and non-timber benefits.

Carbon Sequestration

Carbon sequestration markets are becoming more prevalent every year as the climate continues to change. The Kyoto protocol brought 160 nations together to bring the issues of rising temperatures and more drastic weather patterns into the limelight (IGBP, 1998). Forests have been identified as carbon source sinks, meaning they can decrease atmospheric levels on planet earth. There are two primary methodologies of carbon sequestration: cap and trade systems in which the measured carbon offset is traded or bought by other companies, and carbon pricing in which an attempt to quantify how much one should be paid for their forests

sequestering carbon in dollars (Gren & Zeleke, 2016). A study completed by Oliver et al. (2014) suggested that CO2 credits should be offered to land owners at a landscape level where additional carbon stored would be stored in forests, while also offering builders CO2 credits for substituting wood for alternative building materials. Optimal age harvesting proves to sequester more carbon than in combined products from stands are not harvested at optimal ages (Oliver et al., 2014). Longleaf is a species of consideration for these markets due to their naturally longer rotation ages, denser wood, and carbon intake. A study by Benecke et al. (2015) proved that increased rotation age increased carbon storage in longleaf stands, as well as site index increasing carbon storage with higher site productivity.

Alavalapati et al. (2002) used the notion that public agencies will provide payment for the services of these forests. Estimates for silvicultural carbon sequestration costs fall between $2 and $56/ton when creating plantations (Alavalapati et al., 2002). This cost would be allocated in taxes due to the public nature of carbon ecosystem services. Landowners would be paid per contractual agreement that every year longleaf stands accrue more volume and the dollar amount per acre increases. Although this study did not prove the financial return of longleaf plantations were greater than slash, the amount of carbon sequestered was more than that of slash pine. The longer rotation age of longleaf also surpassed slash in volumetric biomass which was where carbon would be stored.

Silvopasture has also been studied as an option to reduce greenhouse gasses. As the name suggests a cross between ranching and forestry not only produces a competitively economic option but also sequesters carbon with comparative levels to traditional forestry. With the price of $50/ton this alternative shows the correlation between timber rotation age and landowners

decision to lengthen the rotation. This allows for more biomass production, thus increasing both volumetric timber products and increased carbon sequestration (Stainback & Alavalapati, 2004).

Plantations have also been studied in the returns that they bring both in monetary value of timber and of carbon sequestration at the stand level. Specifically non-industrial private forest landowners take notice of the opportunities to come by offering carbon offset credits to large carbon emission companies. A loblolly study showed that as the rate of return increased from 2.5 to 15% these revenue opportunities would actually shorten rotation age on high quality sites or stay the same on low quality sites if the carbon payments are calculated into soil expectation value. The study used the alternate rate of return to compare to the thinning and harvest of plantation timber with the added benefit of carbon payments ranging from 0-100$/ton of carbon sequestered (Huang & Kronrad, 2006).

Parajuli and Chang (2012) analyzed the effect of joining timber rotation with carbon sequestration payments in an uneven aged loblolly stands. The study's results showed the optimum management regimes that occurred under the assumptions of their of model. Utilizing the Generalized Faustmann model allowed the optimal rotation age as well as the most economically beneficial LEV. The less productive sites' financial returns were more effected than more productive sites, and optimal management of the stands proved to have more effect on returns than stumpage price (Parajuli & Chang, 2012).

Wildlife Habitat

Longleaf is a renowned wildlife habitat for a plethora of species from white tail deer (*Odocoileus virginianus*), several species of turkey (*Meleagris gallopavo silvestris*), and most famously the Bob-white quail (*Colinus virginianus*). Even aged plantations depending on management objectives include wildlife in the form of game species and non-game species.

Typically if the stand is to withhold wildlife game species the stand needs open habitat, forage, and cover, typical of a stand containing between 50 and 70 feet of basal area (Landers et al., 1995). If wildlife is the major objective of the stand then basal areas can be as low as 30-40 feet per acre, a common stand volume for species such as the Red Cockaded Woodpecker f. Although not ideal for timber or straw production, economic incentives are available through federal programs to assist with RCW management. All other species are desirable species of game that inhabit the timber operations of longleaf stands in the south as a potential revenue source.

One particular case study in Thomas county Georgia shows the value of the hunting plantation in comparison to the revenue produced by timber, which factors into many land decision variables for southern landowners (Kush et al., 2005).

Another case study via the Georgia Forestry Commission shows that in comparison to traditional timber products alone the NPV can be converted from -$59/acre to $205/acre with the addition of hunting lease and pine straw revenues (Sunday, 2012).

There is no question that hunting revenues can be a profitable revenue stream in creating a working timberland model. With twenty-one percent of southern timberland being in plantation style forestry, covering nearly 45 million acres, there is vast opportunity to fine tune a wildlife management plan into the working forest (Davis et al., 2017). One particular study was done in coastal plains and the pine Flatwoods of southern Mississippi, similar to other pinelands with low quality soils. Wildlife such as Bob-white quail and white tailed deer are producing more than 8 million dollars per quail season and nearly one billion dollars per deer season in Mississippi (Davis et al., 2017). Discount rates necessary were also analyzed at two different interest rates, 3% and 5 %. Each planting density was done with wildlife management and timber management.

A primary example, both deer and quail scenarios involved a first thinning in the timber once the stands reached 55% SDI, but the residual basal area left after the first thinning for deer was 9m^2/ha compared to the 7m^2/ha that quail required. Another primary example in this study is the difference in burn intervals: every five years for timber management, every two years for quail scenarios, three years for quail timber scenarios, and so on. The valuation method utilized LEV calculations to account for the net present value of a single management regime as well as repetition of timber crops grown on the land into perpetuity, allowing for scenario comparison that involve different rotation lengths based on the management scenario. The tradeoff between hunting habitat and timber growth is done in the form compensatory lease rates required to offset the revenue loss from conversion of timberland to wildlife management land.

Pine Straw

Pine straw production from longleaf stands could make longleaf pine management financially attractive. In North Carolina alone the income from pine straw raking estimates between $30 and $50 million dollars annually (Johnson, 2011). One example would be including wildlife such as the RCW and pine straw harvest in the same management model. Pine needles are sought after by many users including homeowners, landscapers, and anyone with a desire to cover ground without the use of wood chips or chemicals. Wildlife and straw management requires a longer stand rotation between 60 and 80 years for feeding habitat and between 100 and 120 for nesting (Roise et al., 1999). Straw operations can begin as late as age 20 and as early as their first productive litter fall (Roise et al. 1999, Johnson, 2011). Lastly a major option lies with the multiple objectives of silvopasture. This style of ranching includes the production of timber, cows for beef or dairy products, and straw raking (Stainback & Alavalapati, 2004).

The minimum basal area required for longleaf straw production usually falls around 90 square feet of basal area for pine straw production. Harvesting operations can also be found utilizing stands with 100 square feet of basal area (Roise et al., 1999). Other traditional products of longleaf plantations include pine straw revenues. Many objectives are planned around this harvest due to the immediate income that this practice provides. Pine harvest can start as early as age 10 at a projected cost of $50 dollars an acre to include fertilization of the soil due to nutrient removal from the pine straw harvests (Alliance, 2016). The dollar amount per acre increases with the age of the stand. Moderate pine straw yield assumptions include breaking even at 6, $75/acre at age 10, $100/acre at age 15, and $125/acre per year at age 30 through the rest of the rotation (Alliance, 2016). The case study that provided this information produced the highest rate of return with both cost share and pine production included in their model at $1317/acre analyzed with an NPV at 4.5% and $882/acre analyzed with an NPV at 6%. The following returns were positive at 29% and 30% which mean a profit is likely, the higher the rate the greater the profit.

Another case study in Georgia showed that the addition of pine straw to the production model will substantially increase LEV of up to 35% from the longleaf byproduct (Dickens et al. 2012). The average weight of longleaf straw harvested on their study sites equaled 3400lbs/acre, the main factors affecting production being site quality, basal area, raking prescriptions and determining how to sell the straw (Dickens et al., 2012).

Fertilization has also been a primary tool in producing longleaf straw, thus enabling better site conditions than what occurs naturally via macronutrients such as Nitrogen, Potassium, and Phosphorus. This increases growth and yield of longleaf products if fertilized appropriately for the site conditions. One study on a 250 acre longleaf tract in Louisiana showcased minimal results over a 15 year period utilizing both fire and fertilizer to increase straw production. The

initial increase in straw and outer bark volume occurred when the study began in 1995-1997. The pine straw production rate dropped to 58% of what is expected of a site with similar site conditions of 76Ft^2 of basal area and site index of 86. The frequent prescribed burning was assumed to change soil competition. This resulted in lower growth and yield production in volume outside of bark, height, needle production, and overall growth (Haywood, 2009).

Fire

Bettinger (2011) reviewed the prescribed fire work throughout the southeastern region and found some positive results and many inconclusive results. The most positive correlation of prescribed fire and longleaf stands is the protection from encroachment of woody vegetation, mainly hardwood tree species, from competing against longleaf and making its way into the over story. The more inconclusive results were that both dormant and growing season burns tend to slow the growth rate of young longleaf, can cause high mortality rates in seedlings, and tend to have no net effect of growth and yield on mid rotation and older stands of longleaf (Bettinger, 2011). However, other studies such as those carried out by Robert Addington and others in the Sandhills of Georgia showed no negative effect on the over-story of longleaf and no negative growth affects in a 14-year-old-pine plantation (Addington et al., 2015).

Fire is generally prescribed in both growing and dormant seasons. Each fire is different depending on the fuel load, weather conditions, and site conditions. Other studies showcase that the effect of fire is individually specific. A study carried in the Sandhill's and Flatwoods of northern Florida found that each ecosystem had different responses to burn treatments but that individuals from the same stands also stored their carbohydrates seasonally different than others, showcasing longleaf that has dominate genetics separated from the others of its cohort (Glitzenstein et al., 1995). One commonality is the effect of spring burns on the intermixed

hardwoods of the longleaf forest. Susceptibility to fire during the growing season has proven to be an effective management tool for keeping hardwoods from creeping into the canopy.

Growth and Yield Models

In order to understand growth and yield, land expectation value, and longleaf as replanting options for private forest landowners, a literature review was compiled to develop a proper research question. Modern growth and yield models are based on linear programming and functions of tree growth. One of the most common functions is that of site productivity. A myriad of soil characteristics such as bulk density, composition, and tree species are a few primary characteristics that allow for the determination of tree growth rate over a period of time. This is just one of many aspects that today's growth yield models look at. Other facets of today's models include whether or not stands are generated through volumetric equations such as the growth and yield models out of the Carbon Resources Science Center (Benecke et al., 2015). Models have also evolved to include not only the estimated timber growth but also species specific carbon sequestration. With so many factors involved with the emission of carbon due to an industrial society and uptake of carbon occurring across the planet via our forests, the vegetation model was derived to show the effect that each of these functions of the growth and yield models have on each other (Benecke et al., 2015). With the knowledge of this ability the valuation does not come from just one but many tree species. Each southern yellow pine species, loblolly, slash, shortleaf, and longleaf has the ability to be matched with a site that allows landowners maximum financial returns. With the input of each assumption these models will allow the landowner to determine the best fit for financially, biologically, and personally.

Chapter 4

Methods and Materials

Loblolly pine has been considered the Southern Pine species which maximizes timber production, thus winning the attention of industrial and non-industrial private forest landowners. In order to get longleaf back in popular demand by private forest landowners, research-based information highlighting the economic profitability of longleaf pine is crucial. It is important to explore under what conditions longleaf can compete with other southern pine species. In a world competing for space and resources, the competitive advantage comes with a diverse portfolio of revenue streams. We incorporated revenues from hunting leases, carbon sequestration payments, and pine straw revenues in addition to the revenues from timber production (Figure1). These products are a function of successful timber production in these products require successful timber growth.

Generalized Faustmann Model

The Faustamnn model has been applied to examine optimal management practices across the topics including silvopasture, uneven and even aged pine plantation management, as well as several wildlife and timber studies. Optimizing forest management by stacking potential benefits into timber production is commonly applied in forest economics and management literature. (Buongiorno, 2001; Chang, 1998; Chang & Gadow 2010; Chang & Parajuli, 2012; Forboseh et al., 1996; Hartman, 1976 ; Paudel & Dweivedi, 2021). We created an economic optimization model to evaluate the optimal economic rotation of even aged longleaf plantations. By accounting for a complete profile of potential costs and revenues, a generalized Faustmann model developed by Chang (1998) was applied to estimate the land expectation value in every age, and the age with the maximum land expectation value LEV was selected as an optimal

rotation age. The model takes into account the value of uncertain future land values with the LEV2 which is written in the formula to be a function of LEV1. The generalized Faustmann model was set up as:

Equation one:

$$LEV_1 = \left[P_1(t_1)Q_1(t_1) + \int_0^{t_1} A_j e^{r_1(t_1-j)} dj - C_1 e^{r_1 t_1} \right] e^{-r_1 t_1} + e^{-r_1 t_1} LEV_2$$

where,

LEV_1 is the land expectation value at the beginning of the first rotation,

$P_1(t_1)$ denotes the stumpage price of t_1-year-old long-leaf pine trees at the $1st$ rotation,

$Q_1(t_1)$ represents the stand volume of different timber products of t_1-year-old long-leaf pine stand at the 1st rotation,

$A_j e^{r_1(t_1-j)}$ is additional annual sources of income and expenses such as pine straw raking and prescribed burn

$(t_1 - j)$ is the time in the first rotation minus the period which is involved with the annual periodic income

C_1 is the stand establishment costs for the $1st$ rotation,

r_1 is the discount rate associated with the $1st$ rotation,

LEV_2 represents the land expectation value at the beginning of the second rotation covering expected returns from future infinite rotations

Growth and Yield Model

To set up the generalized Faustmann model, longleaf plantations were quantified with multiple traditional timber products in the form of poles, saw timber, chip and saw, and pulpwood. We used the Gongalez-Benecke et al. (2015) growth and yield model to generate the volumetric timber data $Q_1(t_1)$ for our four class products, (1-2) 60/40 pole and saw timber ratio

generated as saw timber in the model, (3) chip and saw logs, (4) pulpwood logs. The Gonzalez-Benecke et al. (2015) model was used to estimate timber product volume, pine straw yields, and carbon sequestration levels.

We chose this model to help generate other volumes such as carbon sequestration and pine straw yield to decrease the likelihood of error from generating multiple products to evaluate economic returns from multiple models written with different growth and yield equations. This model has been utilized in other economic studies (Paudel & Dwivedi, 2021 ; Suseata & Gong, 2019). The growth and yield model also allows for prescriptions such as prescribed fire to be included within the models assumptions, allowing us to utilize optimal longleaf management prescriptions (Gonzalez-Benecke et al., 2015). Another reason we chose this growth and yield model is its ability to simulate longleaf stands from planting, based off of optimal silvicultural assumptions which we utilized. The model can also utilize inventory data collection to project growth and yield estimations (Gonzalez-Benecke et al., 2015).

The economic model utilizes both thinning effects as well as prescribed burn regimes into the Gonzalez-Benecke model (2015). The prescribed burns are not to effect the growth and yield of the timber volumes, but do effect stand biomass on the forest floor, coarse woody debris, and understory biomass (Benekce Model User Manuel). To cover a range of scenarios that landowners could face, a 3x3 model was set up to cover a range of site indices at 70, 90, and 101 at base age of 50 years. This model also covered a range of tree plantings at the low to high planting density at 436, 545, and 605 trees per acre TPA, respectively. Similar planting densities have been reported by multiple private and public entities, including the US Forest Service (Larson, 2002). The model was carried out to 70 years to ensure that the generalized Faustmann model was allowed enough time to find the optimal rotation age within each product scenario. To

simulate the longleaf stand the rotation age was set to age 70 in the excel program, as well as the basal area prescriptions Rx1 and Rx2, the choice of a site preparation burn at establishment, and the inclusion of a burn cycle set at age 14, after all entries the program has a "Run Simulation" button to run the program.

Each of these model simulated experiments was also subject to one of two basal area treatments in thinning applications. One thinning treatment (Rx1) was a target and residual basal areas of $120ft^2$ and $78ft^2$, respectively. It infers that when the basal area per acre reaches to $120ft^2$, a thinning would be triggered to bring a residual basal area to 78 ft^2 per acre. Similarly, the second thinning treatment (Rx2) was set at a target basal area of $140ft^2$ with a residual basal area of $90ft^2$ per acre (Kush et al., 2005). Price information was from the reporting agency such as Timber-Mart South and was obtained for pine products for south wide averages in the first quarter of 2021 (Timber Mart South, 2021).

Similarly, three interest rates of 4, 6, and 8 percent were considered in financial analysis to examine the effects of interest rates on LEV and optimal rotation age of longleaf pine management. We incorporated all the initial stand establishment costs, fertilization, and periodic prescribed burning in comparison to the common forestry practices used in even aged longleaf plantations. The stand establishment cost data were obtained from the North Carolina Forest Service Forest Development Program for the statewide private forest landowners. Costs included containerized seedling and planting cost, prescribed fire, chemical control for the first 10 years, and light mechanical preparation on highest planting density of 605 to ensure a viable survival rate (Table1). Containerized seedling costs were on a per tree basis at .195 cents per seedling. To produce 92 percent of the survival the planted seedlings were containerized for the planting crop (Kara et al., 2017). All establishment costs occur at year zero. Implication of the management

paid for at year zero is to be done at the most applicable time to burn, spray, and plant. Future land values, LEV2, associated with the generalized Faustmann model were modeled to represent the increase in site quality with an increase in future land value as $400/acre for site index 70, $600/acre for site index 90, and $900/acre at site index 101. Lastly we conducted sensitivity analysis on the LEV2 at an increase and decrease of 20% of LEV1. This was to compare LEV2 with the inclusion of uncertainty of future variables associated with the longleaf stand. This differs from the other results in that the traditional Fasutmann model is represented by fixed LEV2s as mentioned above. We compared the scenarios one and eight at the baseline scenario of 545TPA at SI 90 to remain consistent with the other sensitivity analysis conducted. The maximum value products scenario of all products included is set up as follows:

Equation two: LEV_1= f(Timber only + Hunting Leases)+ Carbon Payments+ Pine Straw + CRP+ LEV2)

Table 1: Planting, seedling, site preparation, and management costs considered in financial analyses.

TPA		Establishment Cost/Acre	$/Acre
436	LOWSI	Seedling + Planting	149.7
		Prescribed Burn	48
		Chemical Control	63
		Total	260.88
545	MEDSI	Seedling + Planting	171.13
		Prescribed Burn	48
		Chemical Control	63
		Total	282.13
605	HIGHSI	Seedling + Planting	182.72
		Prescribed Burn	48
		Chemical Control	63
		Light Mechanical Site Prep	85
		Total	378.72

Table 2: Scenarios representative of each product economically evaluated in the generalized Faustmann model.

Scenario	Product combinations
1	Timber only
2	Timber + CRP
3	Timber + Hunting Lease
4	Timber + Straw
5	Timber + Carbon Credits
6	Timber + Hunting Lease + Pine Straw
7	Timber + Hunting Lease + Pine Straw + Carbon Credits
8	Timber + Hunting Lease + Carbon Credits + CRP
9	Timber + Hunting Lease + Carbon Credits + CRP + Pine Straw

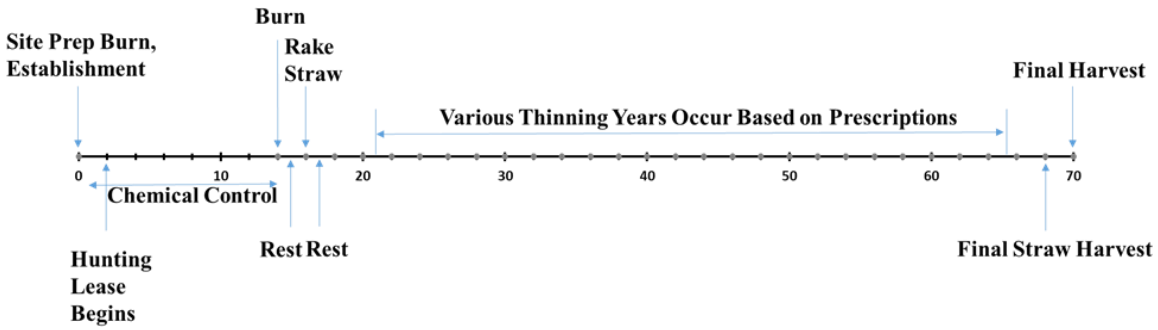

Figure 1: Various management practices considered in the generalized Faustmann model

Forest Carbon Credits

The Gonzalez-Benecke model (Gonzalez-Benecke et al. 2015) was used to simulate carbon sequestration data over the life of the stand. It is an excel based model that simulates timber volume, in situ/ ex situ carbon sequestration, pine straw yields and revenue up to 500

years into the future (Gonzalez-Benecke et al. 2015). To verify our carbon sequestration model as a function of timber growth we consulted with the director of forest carbon manager from The Forestland Group to validate our methods utilizing the growth and yield models sequestration forecast, then converting that into a dollar amount based of The World Bank carbon payment rates (Personal Communication, Worthington, 2021).

The carbon sequestered in tons per acre was evaluated in the development of dollar amount/acre for the carbon credit calculation. To reach the maximum LEV for longleaf timber stands, the optimal rotation age for the monetary benefits of carbon and timber had to be integrated into the same model. The fixed costs associated with joining the carbon sequestration credit market were not included in the carbon model, this model more accurately portrays the large acreage landowner than the smaller by their ability to disperse fixed costs with across a larger property, generating more revenues from larger carbon offset projects. The dollar amount used in this model would be lower than $13/ton for the smaller acreage landowner. The additional timber benefits are necessary because timber growth and carbon sequestration are positively correlated. Policies from the American Carbon Registry are evaluated, In order to mitigate the final harvest a 40% penalty of revenues made from carbon sequestration are to be paid at the time of early harvest or harvest over the set leakage standard for the project (Winrock International, 2015). Carbon tons per acre obtained from the Gongalez-Benecke model were first converted to tons of carbon dioxide per acre by multiplying the molecular weight of carbon dioxide by the net carbon per acre, and dividing by the molecular weight of carbon. The final product was quantified with The World Bank Virginia ETS market price at $13 per ton of CO2 equivalent sequestered per acre. To account for the penalty of harvesting the forest, the market price per acre was multiplied by 0.6 to obtain the final dollar amount from forest carbon credits.

CRP Rental

The four primary programs involved with the planting and cost share programs associated with longleaf are CP36, CP3A continuous, CP3A general, and CREP (Transmittal, 2008). This project quantifies the benefits of CP36 associated with America's Longleaf Restoration Initiative and its stacked benefits to bring the most competitive cost share program to non-industrial private forest landowners in the southeastern states.

Compared with general stipulations, the FSA handbook refers to continuous sign up as a noncompetitive application process that receives yearly funding and applications on a case-by-case basis. If the technical service providers offer cost shares to landowners, they are eligible to receive CRP rental payments for two 15-year periods. This program also allows for two one-time payments per acre that are paid out at the end of the fiscal year before the crop rotation year begins. This payment includes up to 50 percent of the associated stand establishment costs to cover up to 52.5 percent of the rental payment per acre as a lump sum. Although commercial use of forests is not permitted in lands associated with the program, forest management activities improving the forest health are usually permitted.

To quantify the benefits of this program, the average CP36 rental payment was used to calculate both rental periods summing up to 30 years as well as the potential 90 percent cost share reimbursement in the beginning stage. The average CP36 rental payment per acre was reported as $68.48 by the NC FSA database (personal communication Lisa Furlow, April 2021). The onetime lump sum payment consisted of three one-time payments, two were equivalent to 20 and 32.5 percent of the average rental payment per acre. The third payment in this lump sum was 50 percent of the establishment cost associated with the tree plantings. The maximum payout for the CP36 continuous program is $300/acre where the models per acre payment fell

under with the highest once payment equaling $225.31/acre. The onetime payments varied because establishment costs vary with the planting density. Stand improvement treatments improve habitat quality on CRP lands as well as stand productivity (Jones et al., 2009).

One limitation with CRP rental enrollment is that pine straw raking is not allowed in the first 30 years under contract, but reversing this policy is currently in discussion. Hence, we assessed two scenarios that allow forest management activities with and without pine straw harvesting to quantify the difference in returns a landowner could expect if the policy were to be reversed in the future (personal communication Lisa Furlow, April 2021).

Pine Straw

The typical longleaf planting scheme for straw raking is 8x10 or 10x12 feet spacing. If mechanical raking is desired for straw harvests, the common practice is every 5^{th} row of trees to be removed in thinning. This cut should be around 15 feet wide to allow ample space for the harvester and machinery to operate in the stand (Johnson 2011). If not starting from planting then several prescriptions including a mosaic of prescribed burning, chemical treatment, mechanical removal, and labor may be required. The typical rights to pine straw raking are sold as lump sum by leasing their lands bailing rights, raking and hauling to a distributor, or rake and bale and sell themselves.

Pine straw raking was set to four-year cycle of burn- rest- rake- rest in order to maximize both straw and timber yields (Figure 2). The pine straw harvests were carried out through year 68 of the rotation of the forest in order to produce maximum revenues. The harvesting of pine straw was delayed until year 16 to ensure minimal disturbance was to occur to the seedlings while still managing for competing vegetation control. This also kept the maximum amount of litter on the ground to ensure minimal soil nutrients were taken off the site while the trees were in established

stages of development. The four year rotation was set to bring income at the beginning of the rotation to ensure revenue was available for any unforeseen costs to the landowner. Assuming that the landowner will minimize cost to increase their net returns prescribed burns costs can be mitigated. Programs such as the Prescribed Fire = Healthy Forests programs are ran by groups such as the Sandhill Prescribed Burn Association. Local chapters depending on what county/state you are in provide all of the tools, equipment, gear, and fuel needed to operate prescribed burning at no cost to landowners (NCFS, Prescribed Burner Training, 2021). A simple request form may be filled out online but landowners need to provide the man power.

To calculate the benefits of the straw income the conservative revenue price of $1/bale to the landowner was used to calculate the revenue. Gongalez-Benecke model reported the litter fall as bales/acre/year. The revenue price for the landowner was multiplied by bales/acre/year to report annual income. To fit this model to the four year rotation the first year's pine straw income was reported at year 16 when the rotation began (Figure 1). Although straw was produced every year the only reported revenues come from rakings every four years until year 68.

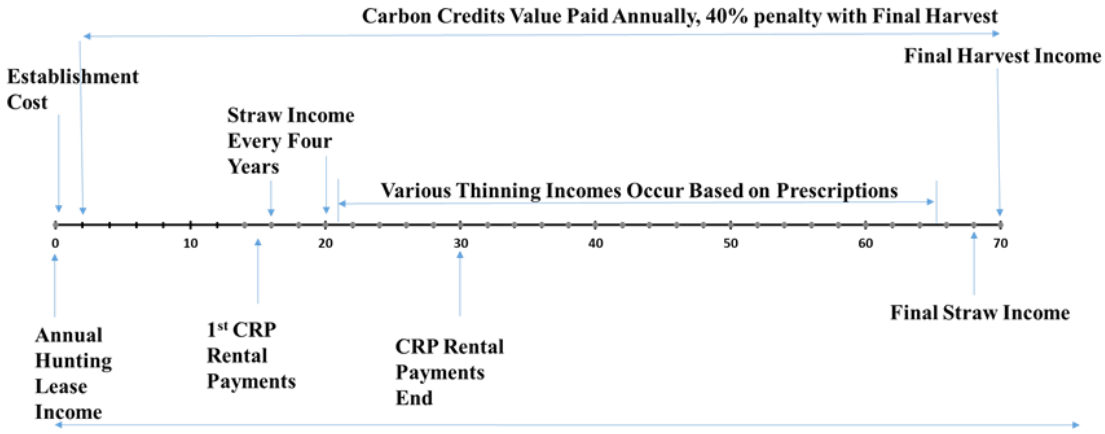

Figure 2: Timeline showing the periodic revenue streams included in the Faustmann model

Wildlife Hunting Lease

Wildlife habitat was assessed as a hunting lease revenue to maximize the benefits of habitat created within the forest managed for timber and straw. Hunting lease assumptions were based on a flat rate at $9/acre as an average of other flat rates reported in the current literature (Davis et al., 2017). Hunting leases are quantified on a per acre basis but vary by the target species, the level of active management for target species, legal and insurance fees. Annual dues also affect the lease income if the hunting club is managed for other services such as lodging, guides, butchery, and multitudes of other professional services. The hunting leases were allowed for purchase at the beginning of year zero for the following hunting seasons staring in year 1 (Figure 1). This method allows time for seedlings to develop and for the game animals to become familiar to the newly planted site.

Chapter 5

Results

The economic implications of managing longleaf for traditional and nontraditional timber products are analyzed in scenarios 1 through 9. Scenario 1 is the assessment of the timber only products of pole, saw timber, chip and saw, and pulpwood. Scenario 8 is the assessment of these products in addition to hunting lease revenue, carbon sequestration payments, and conservation rental payments CRP. Scenario 9 is the assessment of combining all possible revenue streams based on longleaf pine stands. Here we presented only a few scenarios highlighting the main findings.

Scenario 1: Timber Only (Baseline)

Table 3 presents the highest economic return and rotation ages for timber managed under various combinations of different planting densities and land productivities at the 4% interest rate. The highest LEV $1560/acre can be achieved at the economically optimal rotation age of 48 years, if the 545 trees per acre are planted in a very productive land with a site index of 101 feet. However, if a landowner has less productive land (between a SI of 70 - 90 feet), results suggest that only 436 seedlings should be planted per acre to achieve the highest monetary return. In lower productive lands the optimal rotation ages are found to be as early as 40 years when below a site index of 90 feet, whereas in the land with a site index of 90, maximum LEVs can be achieved at year 50.

Table 3: Economic LEV of managing longleaf pine with basal area prescription two for timber production. Evaluated at market price at 4% interest rate.

Scenario 1	(***Timber$***) $/Acre(Optimal Rotation Age)				**Rx 2**
SI(Base Age 50)	Trees Per Acre				
	436 trees/acre		**545 trees/acre**		**605 trees/acre**
Low (70)	200(40)		174(42)		74(48)
Med (90)	710(50)		672(48)		566(54)
Hi (101)	1227(46)		**1560(48)**		959(48)

Scenario 2: Timber and CRP Payments

Table 4 presents the results of timber benefits incorporated with CRP cost assistance and rental payments. The stands associated with CRP assistance had the highest level of return for any single product added to the value of the timber (Figure 3). The maximum economic return of $2921/acre at an economically optimal rotation age at 48 years, can be achieved if planted on high quality land (SI 101 feet) at 545 trees per acre. At the low to medium site quality land (SI 70 - 90 feet), results indicate optimal returns at low planting densities of 436 trees per acre (Table 4). The lowest site quality land (SI 70 feet) indicates that timber should be harvested at 40 years in order to achieve optimal returns. In the medium site quality land (SI 90 feet) the timber should be allowed to grow until age 50 (Table 4).

Table 4: Maximum land expectation values from longleaf plantations managed with basal area prescription two with the corresponding rotation ages under CRP rental payments. Evaluated at market price the interest rate of 4% is considered.

Scenario 2	(***Timber$ + CRP$)*** $/Acre(Optimal Rotation Age)				**Rx 2**
SI(Base Age 50)	Trees Per Acre				
	436 trees/acre		**545 trees/acre**		**605 trees/acre**
Low (70)	1550(40)		1536(42)		1484(43)
Med (90)	2060(50)		2034(48)		1976(54)
Hi (101)	2578(46)		**2921(48)**		2369(48)

Scenario 7: Timber + Straw + Hunting Lease + Carbon Credits

Table 5 presents results from products managed under various planting densities and qualities of land incorporated with scenario 7, which maximized economic returns at the 4 % interest rate. The maximum return of $2554/acre can be obtained from the high quality land (SI 101 feet) by planting 545 trees per acre. The economic optimal rotation for this scenario is found to be 48 years. If a landowner has low quality land (SI 70 feet) then the addition of other benefits allows landowners to increase planting density to 545 trees per acre, at year 48. If land is of medium site quality (SI 90), then optimal returns occur at a lower planting density of 436 trees

per acre. If the land is of medium site quality then maximum returns will occur at year 52, at year 52 (Table 5).

Table 5: Maximum land expectation values from longleaf plantations managed with basal area prescription two for timber, hunting lease, carbon sequestration, and pine straw with corresponding rotation ages. The interest rate of 4% is considered.

Scenario 7	(***Timber$ + Hunting$ + Carbon$ + Straw$***) $/Acre(Optimal Rotation Age)				**Rx 2**
SI(Base Age 50)	Trees Per Acre				
	436 trees/acre		**545 trees/acre**		**605 trees/acre**
Low (70)	888(48)		918(48)		846(48)
Med (90)	1625(52)		1581(48)		1484(56)
Hi (101)	2195(48)		**2554(48)**		1982(48)

Scenario 8: Timber + CRP + Hunting Lease + Carbon Sequestration

Table 6 presents results from longleaf pine management for timber, CRP, hunting leases and carbon credits under various planting densities and site qualities, assessed at a 4% interest rate. The maximum return of $3423/acre can be achieved at optimal rotation age of 48 years if planted on high quality lands (SI 101feet) at a planting density of 545 trees per acre. Low to medium site quality land can produce the highest economic return at the planting density of

436 trees per acre. The optimal rotation length for medium site quality lands is found at year 50, whereas the optimal rotation age is also 40 years in the low productive lands (Table 6).

Table 6: Maximum land expectation values from longleaf plantations managed with basal area prescription two for timber, CRP, hunting leases and carbon sequestration. The interest rate of 4% is considered.

Scenario 8	(***Timber$ + Hunting$ + Carbon$ + CRP$***) $/Acre(Optimal Rotation Age**)**				**Rx 2**
SI(Base Age 50)	Trees Per Acre				
	436 trees/acre		**545 trees/acre**		**605 trees/acre**
Low (70)	1932(40)		1929(40)		1882(44)
Med (90)	2519(50)		2502(48)		2427(44)
Hi (101)	3143(39)		**3423(48)**		2875(44)

Scenario 9: Timber + CRP + Hunting Lease + Carbon Sequestration + Straw

Table 7 presents results from longleaf pine management for timber, CRP, hunting leases, carbon credits, and pine straw under various planting densities and site qualities, assessed at a 4% interest rate. The maximum return of $3915/acre can be achieved at optimal rotation age of 48 years if planted on high quality lands (SI 101feet) at a planting density of 545 trees per acre. Medium site quality land can produce the highest economic return at the planting density of

436 trees per acre. The optimal rotation length for medium site quality lands is found at year 52, whereas the optimal rotation age is 44 years in the low productive lands at 545TPA (Table 7).

Table 7: Maximum land expectation values from longleaf plantations managed with basal area prescription two for all products with the corresponding rotation ages. The interest rate of 4% is considered.

Scenario 9	**(*Timber$ + Hunting$ + Straw$ + Carbon$ + CRP$*)** $/Acre(Optimal Rotation Age)				**Rx 2**
SI(Base Age 50)	Trees Per Acre				
	436 trees/acre		**545 trees/acre**		**605 trees/acre**
Low (70)	1550(40)		1536(42)		1484(43)
Med (90)	2060(50)		2034(48)		1976(54)
Hi (101)	2578(46)		**2921(48)**		2369(48)

Sensitivity Analyses

Varying Interest Rates

The optimal LEVs decrease as the interest rate increases under all scenarios. With assistance of cost share and rental payments, the timberland investment of longleaf still produces a positive return when assessed at 4, 6, and 8% interest rate (Table 8). If only considering the

timber production, the value becomes negative at the 6 and 8 % interest rates. When assessed at 8 % interest rate, the difference between scenario 2 and 8 produces a difference of $231/acre. The other combination of products in scenario 7 did not produce a return at 8% interest rate when compared to the scenarios involved with CRPs. This is denoted by the optimal rotation age occurring at year 0. At a higher monetary value, scenario 2 was less affected by the interest rate than scenario 7 which had a smaller magnitude of dollar return. Scenario 2 had an $1123 decrease in economic returns from 4% to 8% interest. Scenario 7 had a $1230/acre decrease in economic returns from 4% to 8% interest, showing a greater impact of interest on the scenarios without establishment cost assistance, mitigating some of the effect of the interest rate on the establishment cost (Table 8).

Table 8: Optimal LEV and rotation ages from baseline scenario 545TPA at SI 90 with varying interest rates.

Interest Rate	**Timber**	**Timber + CRP**	**Timber + Straw + Hunting Lease + Carbon**	**Timber + hunting lease + Carbon + CRP**
0.04	673(48)	2034 (48)	1581 (48)	2502 (47)
0.06	318 (0)	1285 (31)	678 (28)	1629 (30)
0.08	318 (0)	911 (30)	351 (0)	1142 (30)

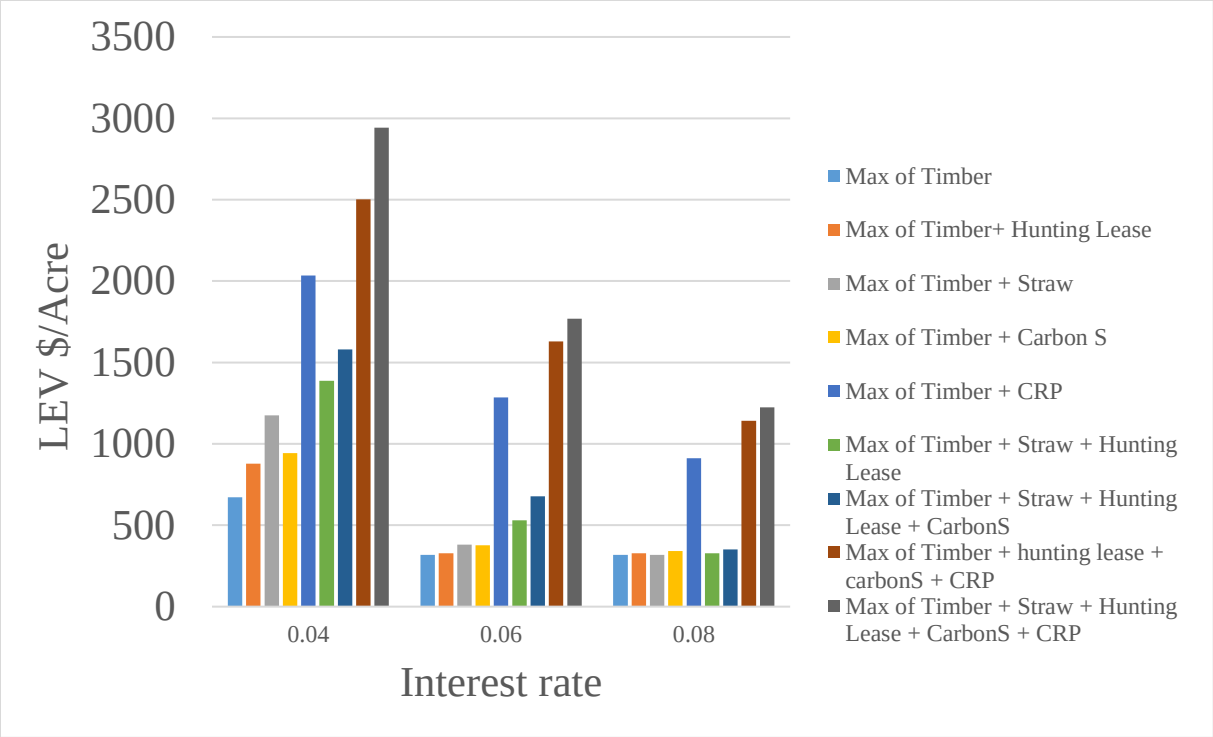

Figure 3: LEVs at the baseline scenario of 545 TPA-Site Index 90 at 4, 6, and 8 % interest rates

Mills and Stiff (2008) also revealed that as interest rates increase, scenarios without timber harvests in southern pine plantations in South Carolina produce negative or undesirable returns for longleaf unless other revenue streams such as pine straw production are added to the economic model. The optimal longleaf rotations in scenarios 7 and 8 are shorter than other scenarios including fewer products. A shorter rotation age will be less effected by the interest rate due to less time the investment can accrue interest at its respective rate. If too little time is allowed for the maximum value of all combined products, this would limit the return also. Accounting for the harvest penalty and all other costs associated with each longleaf product produced, when more revenues were added economic returns increased across the respective

interest rates. When considering all products as the optimal scenario, higher interest rates show a decrease in the value and rotation age, as the interest rate increases from 4 and 6 and 8 percent.

Varying Timber Prices

Table 9: Optimal returns and rotation age from 545 trees per acre on medium site quality (SI 90), varying timber prices 20% above and below the market price, assessed at 4 % interest.

Timber Price	Timber	Timber + CRP	Timber + Straw + Hunting Lease + Carbon	Timber + hunting lease + carbon + CRP
-20%	499 (48)	1860 (48)	1408 (48)	2331 (47)
Market Price	673(48)	2034 (48)	1581 (48)	2502 (47)
+20%	847 (55)	2208 (55)	1754 (48)	2674 (47)

Table 9 presents the economic returns of 545 trees per acre planted on a medium quality site. Each revenue scenario was analyzed under a 20% increase and decrease of market price for longleaf timber. At a 20% decrease in market price the maximum economic return occurred under scenario 8 at $2331/acre. The highest return for a 20% increase in market price occurred under the same scenario at $2674/acre. With varying timber prices, the income from other products produced by longleaf will vary due to timber revenues being accounted into the economic returns. If timber values only were considered, then a 4% interest will allow for profitability at a 20% increase or decrease in market price. If a 20% increase or decrease occurs in market price, then timber values alone produce a positive economic return at 4% interest. Interestingly, the longleaf products from scenario 7 and 8 at a 20% decrease or increase produced

the same rotation age at 47 and 48 years respectively. When timber prices increased 20% scenarios 1 and 2 economic returns and rotation ages increased.

Varying Thinning Intensity

When considering planting longleaf for timber only, the lowest return came from Rx1 at $66/Acre at the rotation of 40 year (Table 10). All things held equal, the same scenario under Rx2 produced a return of $74/acre as the lowest return at the optimal rotation age of 48 years (Table 3). None of 605 planting density scenarios produced returns higher than the other planting densities at 436 or 545 trees per acre (Table 3 and 10). Planting densities greater than 545 TPA have a negative effect on economic returns in all site indices under scenario 1.

If timber only revenue is considered, rotation ages were found to be as short as 29 years at the cost of a smaller return in comparison if you were to wait until year 46 and achieve a $800/acre increase in returns in prescription Rx1. Interestingly, the results suggest that the shorter optimal rotation years occur in scenario 1 (Rx1) produced lower returns than (Rx2). Returns for both prescriptions are nearly identical for timber only with only a difference of $8/acre occurring in the 605 planting density. The optimal rotation years are almost identical for treatments 436 and 545 trees per acre differing only by two years in the 545 TPA treatment. Rx1 reaches its optimal rotation year at year 46, two years before Rx2 reaches its optimal rotation at year 48. Rx2 outcompetes Rx1 in monetary value by $222/acre (Tables 3 and 10).

Table 10: Maximum land expectation values from longleaf plantations managed with basal area prescription one for timber with corresponding rotation ages. The interest rate of 4% is considered.

Scenario 1	**(*Timber$*)** $/Acre(Optimal Rotation Age)				**Rx 1**
SI(Base Age 50)	Trees Per Acre				
	436 trees/acre		**545 trees/acre**		**605 trees/acre**
Low (70)	200(40)		174(41)		1484(39)
Med (90)	538(29)		709(55)		555(50)
Hi (101)	**1338(46)**		1268(44)		921(49)

Returns were analyzed and are outcompeted by higher site quality (SI 101) with Rx2; however, scenario 7 is the only scenario of all nine that showed optimal returns with site index 90 over 101 with Rx1. The basal area prescription Rx1 favored the tree planting density at 545, whereas in the other 8 scenarios, it optimized returns at 436 trees per acre. The highest economic return for Rx1 occurred at $2013/acre at rotation year 60 (Table 11) and Rx2 favored baseline tree planting at 545 TPA as occurred in all other scenarios. The optimal return for Rx2 outcompeted Rx1 at $2554/acre at rotation year 48 (Table 5).

Table 11: Maximum land expectation values from longleaf plantations managed with basal area prescription one for timber, hunting, carbon sequestration, and straw with corresponding rotation ages. The interest rate of 4% is considered.

Scenario 7	**(*Timber$ + Hunting$ + Carbon$ + Straw$*)** $/Acre(Optimal Rotation Age)				**Rx 1**
SI(Base Age 50)	Trees Per Acre				
	436 trees/acre		**545 trees/acre**		**605 trees/acre**
Low (70)	881(48)		1273(68)		772(52)
Med (90)	1842(60)		**2013(60)**		1407(48)
Hi (101)	1989(44)		1769(43)		1822(52)

Scenario 8 produced the most competitive returns as a viable option for longleaf management today. Although the returns are smaller than scenario 9 returns they are still competitive at $3423/acre at 545TPA (Table 6), $3150/acre at 436TPA (Table 12). The rotation age for Rx2 is two years longer at age 48 than Rx1 rotations age at 46 years (Table 6). The difference of $273/acre occurs dependent on which basal area prescription and which planting density is chosen.

Table 12: Maximum land expectation values from longleaf plantations managed with basal area prescription one for timber, hunting, carbon sequestration, and CRP with corresponding rotation ages with. The interest rate of 4% is considered.

Scenario 8	(***Timber$ + Hunting$ + Carbon$ + CRP$***) $/Acre(Optimal Rotation Age)				**Rx 1**
SI(Base Age 50)	Trees Per Acre				
	436 trees/acre		**545 trees/acre**		**605 trees/acre**
Low (70)	1926(41)		1929(40)		1860(38)
Med (90)	2337(28)		2451(55)		2390(48)
Hi (101)	**3150(46)**		3130(43)		2808(52)

Tables 7 and 13 represent scenario 9, the theoretical economic returns if CRP were to allow the harvesting of pine straw on CRP contracted lands. Although this return is theoretical the competitiveness of these returns specifically for Rx2 (Table 7) shows a very competitive economic return at $3915/acre. At $3532 dollars per acre Rx1 is still very competitive however its rotation age is longer than Rx2 which is 44 years. With a greater return and shorter rotation age Rx2 outcompetes Rx1 in scenario 9.

Table 13: Maximum land expectation values from longleaf plantations managed with basal area prescription one for all timber and non-timber products with corresponding rotation ages. The interest rate of 4% is considered.

Scenario 9	**(*Timber$ + Hunting$ + Straw$ + Carbon$ + CRP$*)** $/Acre(Optimal Rotation Age)				**Rx 1**
SI(Base Age 50)	Trees Per Acre				
	436 trees/acre		**545 trees/acre**		**605 trees/acre**
Low (70)	2231(49)		2238(40)		2181(52)
Med (90)	2715(52)		2910(56)		2816(48)
Hi (101)	3326(44)		**3532(44)**		3231(52)

The most competitive results of basal area prescriptions (Rx2 and Rx1) occurred in uniform results across all planting densities that incorporated CRP assistance in scenarios 2, 7, 8, and 9. When different combinations of products were assessed in dollars per acre, returns produced in those scenarios accompanied with the CRP assistance were higher than any of the other product combinations. The 436 tree planting density had 8 scenarios where Rx2 outcompeted Rx1, three scenarios where Rx1 outcompeted Rx2, and one scenario where both basal area prescriptions produced the same economic return (Figure 4). Rx1 outcompeted Rx2 in

scenario 8 at the 436 planting density, where Rx1 had the highest return of $3150/acre and Rx2 returned $3143/acre at site index 101 with a tree planting density of 436 trees per acre (Figure 4).

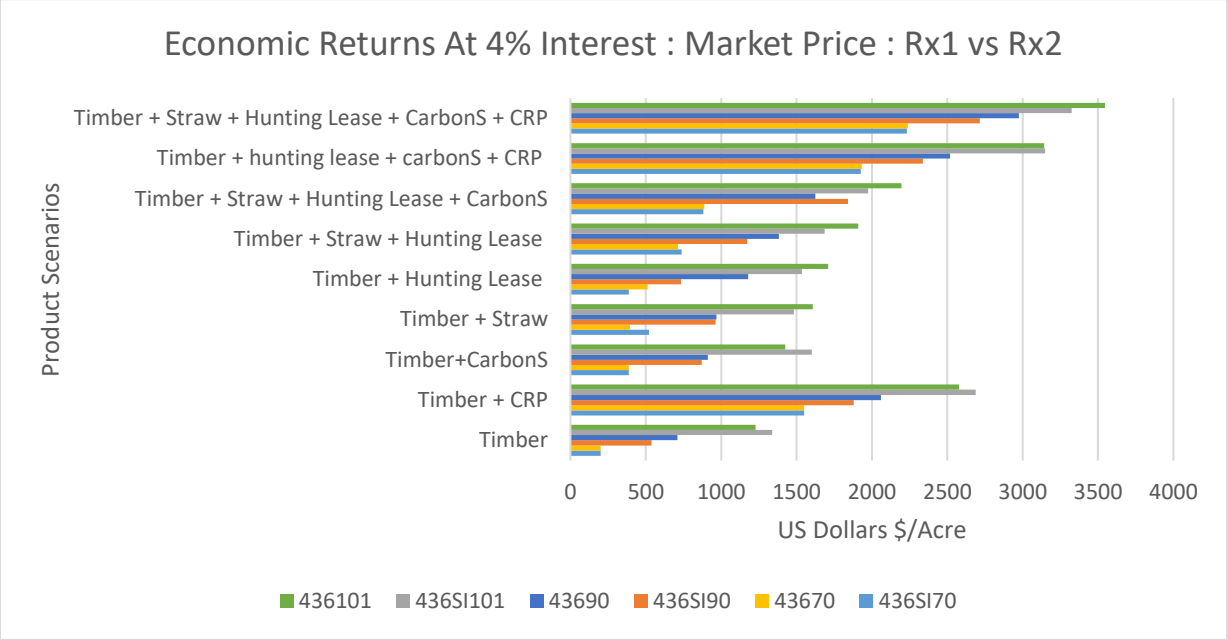

Figure 4: Returns from all product scenarios 1-9 at the 436 TPA (Residual Basal Area 90ft2) and respective high, medium, and low site indices, showing the models optimal rotations returns. 436101= (Rx2) vs 436SI101 = (Rx1).

The 545 tree planting had eight scenarios in which Rx2 outcompeted Rx1, three scenarios in which Rx1 outcompeted Rx2, and one scenario in which they produced the same economic return. Rx1 outcompeted Rx2 at the highest return in scenario 2 at site index 90 with a 545 planting density, in which Rx1 produced $2070/acre versus $2033/acre (Figure 5).

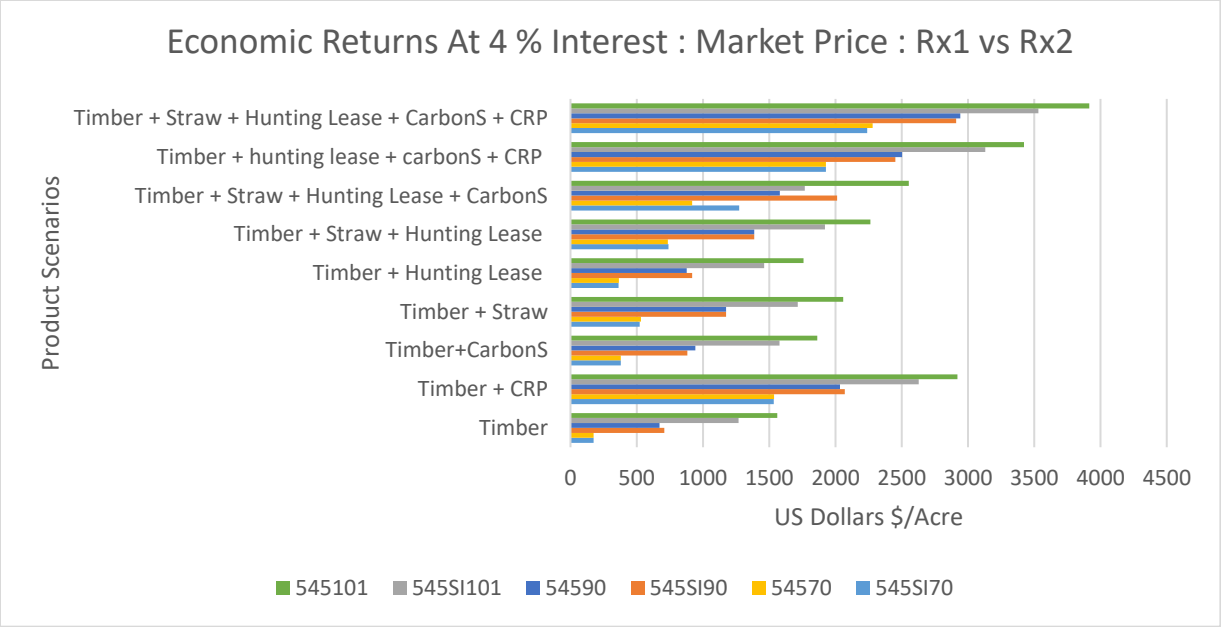

Figure 5: Returns from all product scenarios 1-9 at the 545 TPA (Residual Basal Area 90ft2) and respective high, medium, and low site indices, showing the models optimal rotations return. 436101= (Rx2) vs 436SI101 = (Rx1).

All benefits with or without CRP assistance incorporated with Rx2 outcompeted the all products scenarios with Rx1associated with the 605 tree planting density (Figure 6).

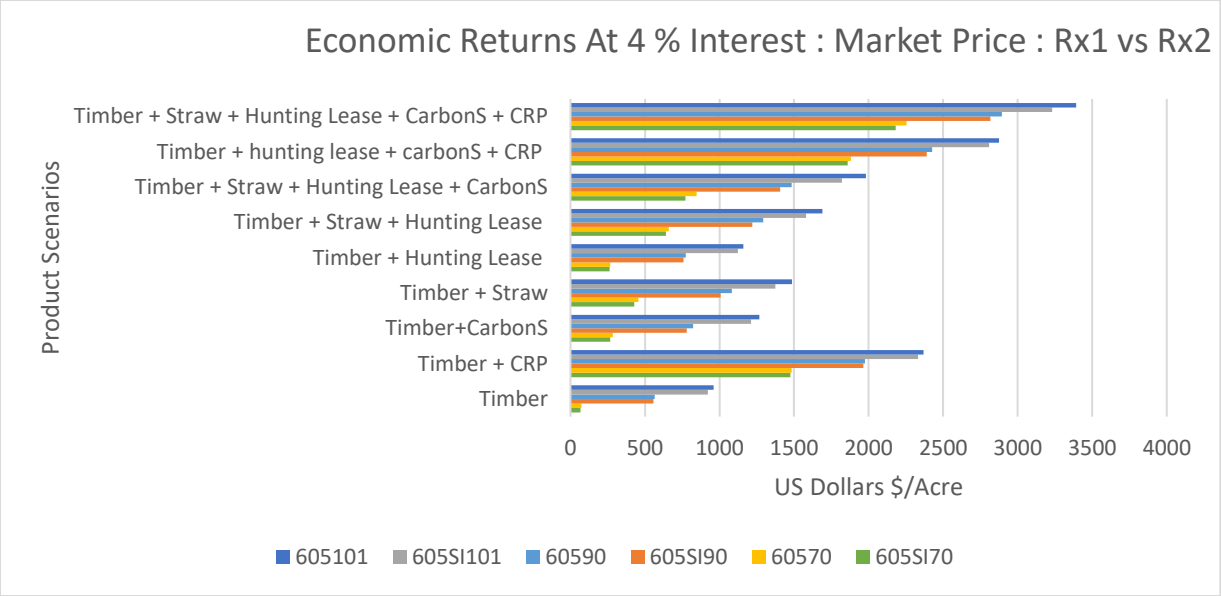

Figure 6: Returns from all product scenarios 1-9 at the 605 TPA (Residual Basal Area 90ft2) and respective hi, medium, and low site indices, showing the models optimal rotations return. 436101= (Rx2) vs 436SI101 = (Rx1).

The comparison of LEV2 to the traditional LEV resulted in an increase in the optimal rotation age when decreasing LEV2 20%, and rotation age remained the same with a 20% increase, if only considering timber value. When only considering timber value, the 20% decrease in future land value, LEV2, lengthened optimal rotation age to maximize the profit from LEV1 due to the decrease in value of LEV2. Rotation age was less effected when considering the multiple revenue streams associated with scenario 8. A variance in 20% in the LEV2 resulted the same rotation age due to maximizing each revenue stream and its associated return at that age.

Table 14: Comparison of LEV2 fluctuation and the traditional LEV.

	LEV2 as 20% lower than LEV1 $/acre(Rotation Age)	**LEV2 as 20% higher than LEV1 $/acre(Rotation Age)**	**Traditional LEV $/acre(Rotation Age)**
Scenario 1	656(55)	687(48)	685(48)
Scenario 8	2807(31)	3071(31)	3319(31)

Chapter 6

Discussion

When more potential revenue streams are added, the longleaf economic model longleaf pine could be an economically viable reforestation option.

Timber, carbon payments, hunting lease, and straw resulted in smaller returns than revenues from timber, carbon, hunting lease and CRP rental payments. Multiple revenue studies evaluated the potential returns on pine plantations with addition of multiple revenue options for landowners (Huang & Kronard, 2006; Parajuli & Chang. 2012; Stainback & Alavalapati, 2004; Susaeta & Gong 2019). Similar to our study, the addition of straw and cost shares increased economic returns from $2554/acre in scenario 7 to $3423/acre in scenario 8 (Table 5 and 6). The addition of multiple payments lengthens the optimal rotation ages in longleaf plantations, compared to the timber-only scenario. The optimal rotation length in scenario 7 and 8 is shorter than of scenarios 3, 4, and 5. Scenarios 7 and 8 both utilized the benefit of growing trees that produce other goods and services. The rotation lengths of the longleaf stands managed for three or more revenues in comparison to the loblolly stand managed for timber and carbon sequestration are shorter (Parajuli & Chang, 2012). Alavalpati et al. (2002) also found similar results in his silvopasture study internalizing carbon benefits with others. Longleaf at respective optimal harvest years occurred in multiple scenarios at 39 – 48 years. As alternate rates of return were assessed by Huang and Kronrad (2006) in loblolly plantations in Texas paired with carbon sequestration revenues, rotation ages decreased as site indices and interest rates increased. Optimal rotation ages for longleaf pine with pine straw, carbon, water, and hunting were found to be between 29 and 38 years, producing returns ranging from $1150/acre to $1540/acre (Paudel & Dwivedi, 2021).

We also found a similar result that certain scenarios such as 436 TPA at the site index of 101 shortened rotation age to 39 in comparison of the lower site index of 70 with a rotation age of 40. This also occurred with the 545 planting density in that as the site index increased the rotation age decreased from age 47 to 40. Factors leading to this result could be the increased accuracy in volumetric projections with the growth and yield model. Another explanation could be that the model decreases the rotation age on quality sites to ensure optimal returns are achieved by both revenue streams, similar to the Texas plantation study (Huang & Kronrad, 2006).

Scenario 8 includes returns from timber production, hunting lease, carbon credits, as well as including CRP's initial planting costs assistance with a rental payment in dollars per acre. With an increase in revenue streams comes a higher return per acre, ranging from timber alone to four revenue streams associated with scenario 8, the returns are higher regardless basal area treatments. A similar result is also reported by Susaeta and Gong (2019) that encompassed revenues attained with longleaf plantations assessing water filtration, carbon sequestration, wildlife benefits and timber, resulting in increased returns. They also discovered that increasing planting density and site indices increased the dollar per acre value of planting longleaf pine (Susaeta & Gong, 2019). The range of longleaf economic returns is reported to be between $557/acre and $1770/acre for all benefits included in the model. In comparison to loblolly pine, they found loblolly to outcompete longleaf by $1866/acre on average, resulting loblolly returns averaging approximately $3600/acre. The returns of their study showed a range of economic returns comparable to our scenario 8, which returned an range of $1881/acre to $3422/acre (Table 6 and 12). The most likely explanation to our studies higher returns occur with the cost assistance of CRP in establishment of the stands and the competitive returns of hunting leases

versus water yield. The other explanation could have resulted from previously examined studies that more revenue streams equal higher returns per acre.

The increase in basal area and the decrease in wildlife habitat are not entirely correlated. Although the timber revenues are used as a baseline for economic gain, there is still room for hunting leases to occur on these longleaf plantations. A study in Mississippi showed that there is a value in managing timber and producing wild game in an even aged stand management (Davis et al., 2017). The first 10 years will be accessible to set up one's property for a hunting lease in their model. Shortly after canopy closure occurs a thinning is required in order to ensure the proper growth of timber. A mosaic of logging trails as well as thinned stand areas allows deer, turkey, and other wildlife species to travel through stand foraging on new growth popping up through the cut over.

Finally, once the stand is fully regenerated, neighboring forests act as a shelter for wild game while the regenerated stand now acts as a food source. All of these scenarios allow for a hunting lease to be in place during the life of the investment in the longleaf stand. Scenario eight proves to be the highest applicable return for non-industrial private forest landowners. The landowner can choose for a shorter rotation with the 436 TPA with an optimal return of 3150$/acre at year 46. The economically optimal option with hunting leases occurs two years later with a return of $3423/acre, depending upon how soon the landowner needs their returns determines age (Tables 6 and 12). Similar results are reported in the Mississippi study from their optimal timber and hunting lease scenarios ranged returns from $3200 - $1985/acre (Davis et al., 2017). The addition of pine straw, carbon, and CRP assistance explains the higher returns that occurred in our scenario 8, but if compared to results from this study scenario 7 show similar returns are reported (Table 5 and 11).

Site Index and Planting Density Directly Effects Timber Volume

The planting density at 545 TPA allowed for more thinning in the treatments that had either 90 or 101 site indices. This correlated with Gonzalez-Benecke et al. (2015) in which mortality occurring in higher planting densities in longleaf plantations at 1500 trees planted per hectare (Gonzalez-Benecke et al., 2015). The greatest returns came from these higher site qualities; another correlation that was reported in Gonzalez-Benecke et al. (2015) was that the higher site quality also increased growth rates which would lead to higher density induced mortalities after canopy closure with higher planting density. This is similar to the results achieved by our economic model in that the financial returns are minimal for the higher planting densities when only considering revenues from harvesting timber alone due to the costs associated with plantings. Timber only scenarios achieve more competitive returns at $1338 and $1560 per acre with the 436 and 545 tree planting densities compared to $959 and $921 from 605 TPA across both Rx1 and Rx2 thinning intensity (Table 3 and 10).

An increase in the value of timber alone and other scenarios is positively correlated with the increase in the site index. Both 436 and 545 planting densities show LEVs at $1227 and $1560/acre. This correlates with various site projected indices completed on old fields, machine prepped, and cut over sites in Georgia by showing that higher quality lands can produce more with an appropriate planting density and site preparation (Dickens et al., 2017). At 605 trees per acre, the LEV decreases across the site indices of 70, 90, and 101. The land with site index 101 feet yields the highest return at 959$/acre. LEVs associated with the 436 planting density at $710/acre at site index 90 were found to outcompete LEVs associated with 545 and 605 TPAs at $672 and $566. Similar results were reported in Gonzalez-Benecke et al. (2012) that early survivability in the stand age was consistent, in that the end of the rotation at age 70 showed the

variable survivability as planting density increased from 566 to 607 trees per acre. The decrease in LEV associated with an increase in planting density follows findings in Gonzalez-Benecke et al. (2012) that higher planting densities equal lower survival rates through the rotation age. Similar to this study, the baseline of economic returns from Parajuli and Chang (2012) was reliant on the value provided from timber production. The maximum LEV from loblolly pine plantations when only considering timber harvest value was $1191 per acre (Parajuli & Chang, 2012). The longleaf pine timber only returns are representative of wood grown to each of their respective prescriptions with a maximum return of $1560/acre.

Straw revenues extend the rotation ages longer than Timber only rotations, but carbon benefits lead to shorten rotations.

At the price point $13/ton for carbon credits, the rotation age is shorter than optimal timber rotation ages or in some cases had the same optimal rotation age as timber only. The fixed upfront costs of entering the carbon market can be substantial to that of a small private forest land owner. The results of this study are comparative to that of large private landowners in that these costs can be dispersed by returns already occurring from the land. A substantially smaller $/acre amount would be applicable with appropriate costs assumed by smaller acreage land holders. The economic returns when pairing carbon sequestration payments with timber were higher than if only considering timber revenues. A shorter rotation age presents carbon sequestration as an advantageous revenue stream to the timber landowner, because the return was higher and liquidated at an earlier age than the timber alone.

Straw revenues paired with the harvest of the stand later in optimal rotation years resulted in higher returns than those associated with carbon sequestration and timber. The rotation ages were extended 48 years and beyond in order to keep the inflow of revenues from straw harvests.

Straw revenues accompanied with timber extended the optimal rotation age up to age 64 in certain straw revenues associated with Rx1 and up to age 56 with Rx2, both surpassing the maximum optimal rotation age for carbon sequestration at year 48.

The extension of optimal rotation length is due to the value brought to the economic returns associated with longleaf straw. The longer rotations allow the four year harvest cycle to occur until the effect of the respective interest degrades the return from the value of the straw harvested and timber grown. Similar results were found in comparison to the economic study of longleaf and slash pine straw (Paudel & Dwivedi, 2021). Optimal longleaf and straw revenues alone were not assessed in this study therefore the closest comparison lies within their scenario 4 and 5 and with our scenario 7 comparative of timber, straw, carbon, and hunting lease revenues. Their optimal return results were between $1570/acre and $785/acre whereas our study produces financial returns ranging from $845/acre and $2554/acre. While the economic returns overlapped, the biggest difference occurred in the optimal rotation ages. Our study showed 48 to 56 years to be the optimal rotation age, while theirs was between ages 23 and 38. The closest similarity rotation age produced within these two studies occurred with Rx2 at the 436 and 545 tree planting density that both had a decade difference between studies.

As interest rates increase, rotation age and economic returns decrease.

The interest rate is an influential factor in any financial analysis. At the interest rate of 4%, the timber only scenario is a viable economic option showing positive returns. Timber only was not a viable option at 6 and 8 percent discount rates, which was shown in the model by the optimal return which occurred at rotation age 0 (Table 9). Similar results were reported in Mills and Stiff (2008) which showed a positive return at their 5 percent discount rate where as 7

percent produced negative returns. Scenario 7 also did not produce a positive economic return at the higher interest rates even when paired with multiple revenue streams.

Similar results were found in that LEV decreases as interest rates increase even with multiple revenue sources from longleaf stands Paudel and Dwivedi (2021). With or without pine straw raking, longleaf became less and less competitive as interest rates increased, whereas the addition of revenue streams such as hunting lease, straw and carbon sequestration positively affected LEV (Paudel & Dwivedi, 2021). Scenarios 2, 8,and 9 showed positive economic returns at every interest rate. This is likely due to the cost assistance that occurred at the beginning of the rotation in scenarios that were associated with CRP cost share and rental payments. Economic returns both remained positive, associating cost share assistance with pine straw revenues in longleaf (Y. Li, Personal Communication, March 2021).

The economic returns for longleaf decreased as discount rates increased but the returns remained positive when discount rates were increased from 4 to 6 percent. Longleaf also outcompeted loblolly and slash under their model's assumptions (Y. Li, Personal Communication, March 2021).

Market price has a direct influence on economic returns with this model, with timber as the baseline.

The development of this model was based on the use of timber returns from an even aged plantation. The scenarios were representative of revenue streams that occur in the addition to revenues from timber. The price fluctuation was well represented across all scenarios by economic returns that occurred within each fluctuation. With a 20% increase in timber price the most notable return difference occurred in scenarios that had less revenue streams. Higher timber prices lengthen rotation ages in scenarios with less revenue stream. When timber prices

decreased by 20% optimal rotation age stayed the same as it was with market price with scenarios including more stand products (Table 9).

Our findings differed from the results of an economic assessment of only saw timber and pulpwood (Forboseh et al., 1996). The results of their Faustmann model showed a decrease in optimal rotation age as the timber price increased. This likely results in the extension in rotation age as the model is set up to find the most optimal economic return at an optimal rotation age for multiple products. As timber prices increase, an increase in rotation length allows timber volumes to become fully developed before harvest. This allows time for the harvest of the non-timber benefits as well. The quality of longleaf timber is rarely pole quality by age 30. It does not make sense to harvest other than what needs to be culled to ensure the desired percentage of poles and saw timber is produced out of the stand. This also explains the variation when including the cost assistance of the CRP program in that rental payments occur through year 30. Although the program payments are no longer occurring, the lack of effect on cost from the interest rates allow further development of the timber to a biological maturity ensuring that per tons rates are also maximized. As revenue streams increase with the management of timber stand the variation in optimal rotation age decreases. The financial maturity of multiple revenues is reached quicker than that of one revenue stream.

The addition of CRP assistance allows for all longleaf products to become more profitable with a lesser establishment cost.

Scenario 2 incorporates the benefits of harvesting the timber after the two 15 year cycles of rental payments from the Conservation Reserve Program are complete. While it is not a common practice, the allowance of timber stand improvements such as thinning are permitted if the improvement is deemed appropriate by an associated forester and or technical service provider

associated with administering the CRP rental payment award and cost share. As stated in the FSA handbook, once the second rental payment period is complete, after one year of receiving the final rental payment, the tree stand is no longer eligible for application of CRP rental funds and the forest is under full ownership of the landowner. However if forest harvests occur during the rental payment periods the landowner is liable to pay back the establishment cost share awarded at the beginning of the stand establishment.

Just as in our scenarios 2 and 8, Dickens et al. (2021) also compared the outputs of longleaf plantations to that of loblolly plantations with and without straw as well as with and without cost share assistance. The cost share program evaluated was the Environmental Quality Incentives Program EQIP and CRP program, which assist landowners with up to 50 percent cost share to establish their longleaf stands. With pine straw harvesting and no cost share assistance, meaning that only timber and straw values were quantified at full cost to the landowner were considered, loblolly outcompeted longleaf respectively at $954/acre versus $482/acre. EQIP and CRP rental, and cost share were quantified in the establishment cost of longleaf. The offset cost allowed pine straw revenues in addition to timber to outcompete loblolly $1502/acre versus $1373/acre in respect to the their assumptions. Similarly CRP rental payments were assessed at their respective rates made in the modeling assumption. Results from the study concluded that with financial incentives available to landowners who want to plant longleaf into a working forest on their native range, a higher return at 38.9 % with pine straw and a return rate of 37.4% without pine straw on a 45 year rotation (Email Communication, Yanshu Li, March 2021).

Regardless of assumptions, the initial rate of returns will always produce higher levels of income with less costs accrued at the front end of the life of the investment. Scenario 2 produced an optimal LEV of $2921/acre when timber was quantified with CP36 cost share assistance and

rental payments. The results from this scenario show the effect of minimizing upfront cost to establish the stand the returns follow a similar pattern to that of timber only scenario in that the 436 planting density shows the highest returns at the low site index at $1550/acre and the medium site index at $2060/acre. The 545 planting density produces the highest return at the highest site indices $2921/acre. The 605 plantings show the lowest returns across all three site indices with the highest return occurring at $2369/acre, just as scenario 1 did (Table 4). Pine straw revenues if permitted on CRP lands would incentivize more landowners to choose longleaf to replant in respect to their economic returns (scenario 9). The highest returns occurred in scenario 9 for both basal area prescriptions Rx1 and Rx2. As the number of revenue streams increased so did the returns. The highest returns occurred in the 545 TPA treatments with a site index 90 at $3532/acre (Rx1) and a site index of 101 at 3915$/acre (Rx2) (Tables 7 and 13). While these are proven to be the highest returns this return is theoretical. Current policies included in the CRP rental program do not allow pine straw harvest off of stands established by any CRP program funds. This policy was changed in the past 10 years according to the interview conducted with the Raleigh Farm Service Agency representative.

Chapter 7

Conclusions and Recommendations

The main goal of this project was to evaluate economic profitability of longleaf pine management by incorporating timber and non-timber revenue options. One consideration with this study is that pole markets are common in the southeast but they are not always accessible to everyone interested in planting a longleaf stand. The results of this project were based on a 60:40 pole to saw timber distribution within the saw timber age class. Without access to a pole market these results could vary due to decreasing price per ton paid for saw timber versus pole timber. With current southern yellow pine prices and an in depth review of the workings of multiple benefits that are produced in even aged longleaf plantations, we investigated optimal rotation age and economic return under various combinations of revenue options. We employed the generalized Faustmann model which is flexible in terms of incorporating variations in timber growth, prices and other market factors from one rotation to another.

Multiple assistance programs are available to landowners to encourage them to plant and manage longleaf pine throughout its historical landscape in the southeastern United States. These assistances (such as CRP) allow for longleaf pine management to be more economically attractive to landowners. Site productivity generally plays a role in determining planting density. Lower site quality returns can be maximized with a 436TPA planting densities. A medium to high site quality produces greater returns with the 545TPA planting density. Planting a longleaf stand to reap the benefits of carbon crediting is more advantageous then timber alone, but not more advantageous than with straw.

Multiple questions arise as to whether landowners want a quicker return or a higher return, or if they want to keep their forest for longer than the suitable loblolly investment, or do

landowners have the ability to participate in the emerging carbon markets? The answer to these questions reside with the landowner's objectives but if stacking benefits accrues a higher return this study's findings provide useful guidance for landowners to make an educated decision. Tapping into all available revenue options would produce the maximum LEV across the four primary scenarios; two, seven, eight, and nine. All three of these scenarios included benefits from the cost share and rental payments offered by the CRP. The interest rate had less effect on these product scenarios because of the reduction of the upfront costs. These costs included up to 90% coverage of planting costs, which is likely the main reason for such higher rates of returns, compared with other scenarios which accrued the full stand establishment costs.

If longleaf pine straw markets are permitted once again in accordance with CRP assistance, obviously the returns produced in this project are competitive at a longer rotation. With the CRP assistance, landowners are available to start a pine straw business at a minimal cost to the landowner. The age of harvested pine straw, starting between ages 8 and 16, allows for carbon sequestration to occur in the growth process of trees. As the straw is harvested, minimal carbon can be removed from the site in the form of raking. While many studies show the economic returns of longleaf pine being outcompeted by loblolly, this data can be skewed by the lack of consideration of proper management, stacking multiple benefits, and proper communication of economic resources available to landowners.

To compare the validity of this economic model and its benefits, a follow up study should use the growth and yield data projected by another model of equivalent quality in the volumetric equations of the longleaf stand. Models that qualify for effective results include FORsim or the use of the US Forest Services Forest Vegetation Simulator. The comparison of the optimal financial analyses using two different growth and yield models could (1) prove the validity of the

economic model as a tool to project economic returns for landowners who interested in planting longleaf and (2) show areas of improvement that future growth and yield models require to better project returns from longleaf plantations.

Recommendations for planting longleaf pine include setting up longleaf plantations for multiple revenues including pine straw, hunting lease, carbon crediting, and timber products. Other values such as water filtration yield could also be added to a multiple products model available with longleaf. Planting longleaf can be an economically attractive option to landowners with or without cost share assistance, depending upon the objectives of landowners. The most viable planting density to use for the medium and high site quality is 545 trees per acre. If site quality is low, then one should consider using 436 trees per acre to ensure maximum value is derived from the investment.

For policy makers, minimal carbon will be released if straw harvesting were to take place as a management tool for the forest floor. The distribution of pine straw in an urban landscape setting allows the nutrients from the straw to be released on a large scale by distributing the product to a demanding public while gaining both public, private, and family operation economic gain. If CRP enrollments were to allow pine straw harvesting the enrollment of longleaf acres would likely increase. Landowners would receive annual and periodic returns with use of straw and carbon credits while the timber develops, also likely to increase landowners participation into the programs associated with longleaf acres available today such as CRP and EQIP due to economically attractive returns. With an increase in participation, these programs would be an opportunity to increase longleaf acreage, restoring some of the historic southeastern natural longleaf range.

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APPENDIX

Table 15: Economic optimization of managing longleaf pine timber and hunting leases with basal area prescription two. Evaluated at market price at a 4% interest rate.

Scenario 3	**(*Timber$ + Hunting$*)** $/Acre(Optimal Rotation Age)				**Rx 2**
SI(Base Age 50)	Trees Per Acre				
	436 trees/acre		**545 trees/acre**		**605 trees/acre**
Low (70)	388(41)		366(43)		267(48)
Med (90)	912(50)		877(55)		774(55)
Hi (101)	1424(46)		**1760(48)**		1159(49)

Table 16: Economic optimization of managing longleaf pine timber and hunting leases with basal area prescription one. Evaluated at market price at a 4% interest rate.

Scenario 3	**(*Timber$ + Hunting$*)** $/Acre(Optimal Rotation Age)				**Rx 1**
SI(Base Age 50)	Trees Per Acre				
	436 trees/acre		**545 trees/acre**		**605 trees/acre**
Low (70)	388(41)		363(41)		262(47)
Med (90)	734(52)		918(57)		758(50)
Hi (101)	**1535(46)**		1462(44)		1123(50)

Table 17: Economic optimization of managing longleaf pine timber and pine straw with basal area prescription two. Evaluated at market price at a 4% interest rate.

Scenario 4	**(*Timber$ + Straw$*)** $/Acre(Optimal Rotation Age)				**Rx 2**
SI(Base Age 50)	Trees Per Acre				
	436 trees/acre		**545 trees/acre**		**605 trees/acre**
Low (70)	513(48)		532(48)		455(52)
Med (90)	1179(52)		1175(56)		1082(56)
Hi (101)	1710(48)		**2059(52)**		1486(52)

Table 18: Economic optimization of managing longleaf pine timber and pine straw with basal area prescription one. Evaluated at market price at a 4% interest rate.

Scenario 4	**(*Timber$ + Straw$*)** $/Acre(Optimal Rotation Age)				**Rx 1**
SI(Base Age 50)	Trees Per Acre				
	436 trees/acre		**545 trees/acre**		**605 trees/acre**
Low (70)	520(64)		523(69)		428(56)
Med (90)	963(52)		918(60)		1008(60)
Hi (101)	1482(52)		**1715(60)**		1375(52)

Table 19: Economic optimization of managing longleaf pine timber for carbon sequestration with basal area prescription two. Evaluated at market price at a 4% interest rate.

Scenario 5	**(*Timber$ + Carbon$*)** $/Acre(Optimal Rotation Age)				**Rx 2**
SI(Base Age 50)	Trees Per Acre				
	436 trees/acre		**545 trees/acre**		**605 trees/acre**
Low (70)	395(41)		380(40)		285(40)
Med (90)	969(48)		943(47)		823(44)
Hi (101)	1607(39)		**1862(47)**		1266(48)

Table 20: Economic optimization of managing longleaf pine timber for carbon sequestration with basal area prescription one. Evaluated at market price at a 4% interest rate.

Scenario 5	**(*Timber$ + Carbon$*)** $/Acre(Optimal Rotation Age)				**Rx 1**
SI(Base Age 50)	Trees Per Acre				
	436 trees/acre		**545 trees/acre**		**605 trees/acre**
Low (70)	386(41)		380(40)		265(38)
Med (90)	871(28)		882(55)		781(48)
Hi (101)	1602(46)		**1577(47)**		1211(40)

Table 21: Economic optimization of managing longleaf pine timber, hunting leases, and straw with basal area prescription two. Evaluated at market price at a 4% interest rate.

Scenario 6	**(*Timber$ + Hunting$ + Straw$*)** $/Acre(Optimal Rotation Age)				**Rx 2**
SI(Base Age 50)	Trees Per Acre				
	436 trees/acre		**545 trees/acre**		**605 trees/acre**
Low (70)	715(52)		736(52)		660(52)
Med (90)	1383(52)		1387(60)		1294(60)
Hi (101)	1909(48)		**2214(52)**		1691(52)

Table 22: Economic optimization of managing longleaf pine timber, hunting leases, and straw with basal area prescription one. Evaluated at market price at a 4% interest rate.

Scenario 6	**(*Timber$* + *Hunting$* + *Straw$*)** $/Acre(Optimal Rotation Age)				**Rx 1**
SI(Base Age 50)	Trees Per Acre				
	436 trees/acre		**545 trees/acre**		**605 trees/acre**
Low (70)	738(68)		740(68)		641(68)
Med (90)	1172(56)		1388(60)		1220(60)
Hi (101)	1687(52)		**1920(52)**		1580(52)

Table 23: Maximum land expectation values from longleaf plantations managed with basal area prescription one with the corresponding rotation ages under CRP rental payments. Evaluated at market price the interest rate of 4% is considered.

Scenario 2	**(*Timber$ + CRP$*)** $/Acre(Optimal Rotation Age)		**Rx 1**
SI(Base Age 50)	Trees Per Acre		
	436 trees/acre	**545 trees/acre**	**605 trees/acre**
Low (70)	1550(40)	1535(41)	1476(39)
Med (90)	1880(51)	2071(56)	1965(50)
Hi (101)	**2689(41)**	2629(44)	2331(49)