An Economic Assessment of Stand-Level Treatments for Southern Pine Beetle Prevention

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ABSTRACT

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The Southern Pine Beetle (SPB) (*Dendroctonus frontalis*) is a native pest of pine trees in the Southeast US. It is the most significant pest of forests in the region (Fettig et al., 2007). The potential effect of silvicultural treatments on reducing damages from southern pine beetle depends on treatments and the assumed probability of damages in a region. This research evaluated the stand level benefits and costs of prevention treatments used to reduce damages from Southern Pine Beetles.

For the 13 southern states, a broad set of treatments were applied to a set of representative stands to characterize the SPB Prevention Program impacts. The representative stands were used in a growth and yield model and were projected into the future under various conditions and treatments. The products from the growth and yield model were then used to estimate soil expectation value (SEV), which was adjusted to account for the risk associated with the probability of tree mortality from SPB (Martell, 1980). The probability of tree mortality from SPB was generated from United States Forest Service (USFS) Forest Inventory and Analysis (FIA) data across the Southeast (Pye et al., 2008).

Results indicated that planted stands would benefit from commercial thinning treatments when compared to control treatments. Pre-commercial thinning treatments resulted in lower SEVs than the control or commercial thinning treatments for planted stands. Results for natural stands suggested that control (no treatment) led to higher SEVs than commercial thinning treatments. The results suggest that components of the prevention program may not be financially justified in terms of stand level SEVs. However, further research is necessary to determine if the ecological effects of the treatments warrant financial support for the program.

KEYWORDS: Southern Pine Beetle (SPB), Soil expectation value, economic risk, SPB prevention treatments

DEDICATION

To my mom, for encouraging me as a young boy to read books like “The Kweeks of Kookatumdee.”

BIOGRAPHY

Nathaniel Naumann was born in Alaska. It was there that he developed a deep lasting love and relationship with the natural world. He loved to play in street puddles, climb trees, and watch the wildlife around him. The skills that were once exhibited in play have blossomed, and now exposed a new realm of scientific discovery that continues to open his eyes and bring a smile across his face. He served his country in the military before attending graduate school. He received a great opportunity in the ATLANTIS Program which afforded him the ability to attend the University of Helsinki, the Swedish University of Agricultural Sciences, and North Carolina State University. He is now looking for opportunities to make the best of his education.

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CONTENTS

INTRODUCTION

Dendroctonus frontalis Zimmerman is a small bark beetle aptly named in the "tree killer" genus that is native to the Southeastern United States (Hain et al., 2011). It is the number one insect damaging pine trees of the Southeast (Ward and Mistretta, 2002). There are 214.6 million acres of forest land in the Southeast, and 96 million have pine forest types (Guldin, 2011). The Southeastern U.S. is primarily comprised of Non-Industrial Private Forestland (NIPF) owners, and ownership by NIPF owners comprises 70% of all timberland in the region (Mayfield et al., 2006). The vast majority of landowners, 85%, in this area own less than 50 acres making comprehensive SPB prevention techniques difficult (Mayfield et al., 2006). Mayfield et al. (2006) found that management declined noticeably with owners of tracts smaller than 100 acres.

Reports of catastrophic SPB outbreaks have occurred since the late 19th Century (Chellman and Wilkinson, 1975). The SPB has successfully been able to attack and reproduce in over 20 *Pinus* species (Coulson et al., 1999). The insect is a native pest that historically evolved with its host pine (*Pinus sp.*) (Hain et al., 2011). In the past, SPB populations relied on disturbances to reproduce at low rates. Since the arrival of Europeans, much of the Southeastern U.S. forest structure has changed from fire dependent, late successional species such as oaks, hickory, and longleaf pine to less fire tolerant species such as loblolly pine and early successional hardwoods (Hain et al., 2011, and Lafon et al., 2007). In addition, the natural fire regime of frequent low intensity fires has been altered to a regime of fire suppression (Hain et al., 2011). The results of the forest composition change and soil erosion have resulted in epidemic SPB outbreaks (Hain et al., 2011; Chellman and Wilkinson, 1975; and Schowalter and Turchin, 1993).

In a recent outbreak, 1999-2003, the Southern Pine Beetle (SPB) killed trees estimated at over $1 billion in the Southeast (Nowak et al., 2008). As a result of the widespread damage from the 1999-2003 outbreaks, the SPB Prevention Program was created to proactively reshape the forests of the Southeast to deny SPB populations the opportunity to exponentially grow. One piece of the program is a cost share funded by the United States Forest Service (USFS) and state governments. Funds are distributed to the 13 states of the Southeast by the USFS. Each state developed and operates a specific program to distribute funds to NIPF owners who are willing to conduct treatments sponsored by the prevention program (Nowak et al., 2008).

OBJECTIVES

The purpose of this project is to economically evaluate if the current SPB Prevention and Restoration Program (SPB PRP) is useful in reducing the economic impact and likelihood of outbreaks from SPB populations. There have been numerous studies covering economics, growth and yield, and SPB proliferation. Burkhart et al. (1986) incorporated all of these tenets, and this project intends to use it as a foundation for project design. The results of this project are intended to build on Pye et al.'s (2011) analysis of the economic effect of the SPB, by providing some insight onto the effectiveness of the USFS SPB PRP. The objectives of this study are to:

- Delineate types of treatments used by southern states to prevent SPB attack and limit damages from attacks
- Model the growth and yield, and economic returns and costs from these treatments using typical stand conditions of the southern states
- Evaluate the economic benefits of conducting these treatments under probabilistic conditions of both attack by and damages from SPB

SOUTHERN PINE BEETLE ECOLOGY

The behavior and ecology of the SPB is complex with many known relationships: symbiotic and antagonistic fungi, mites, temperatures, precipitation, other insects, chemicals, and trees. A genetic evaluation of SPB populations concluded that there is significant dispersal beyond states or forests, and that populations differ more by region than smaller geographic scales (Schrey et al., 2008). Many factors together influence the complex population dynamics of the SPB.

Raffa et al. (2008) pointed out that resources should be managed as biologically important, not according to political boundaries and cycles. Systems that were in relative balance have been disturbed by humans, and management should be limited until ecology of the involved organisms and their environment are understood (Raffa et al., 2008 and Berryman, 1986). Mawby and Gold (1984) expressed that the SPB has two distinct action levels: low and high. These levels of bark beetle populations are characterized as pulse eruptive (Raffa et al., 2008). SPB populations represent the health of ecosystems and anthropogenic interactions (Raffa et al., 2008). SPB levels erupt when sets of feedbacks and thresholds are reached amplifying populations to catastrophic sizes (Berryman, 1986). Liebhold and Tobin (2008) discussed two types of population dispersal: continuous spread and long distance dispersal. Aside from human involvement, environmental factors such as regional stochasticity of host species may be more influential in variations of population levels than climatic factors (Peltonen et al., 2002).

Research by Veysey et al. (2003) suggests that the SPB and Virginia pine (*Pinus virginiana*) may be evolutionarily linked. SPB was found to have a higher larval mortality in Virginia pine compared to loblolly pine despite loblolly having higher resin flows. The authors found that nearly every Virginia pine was attacked and died in the test stands compared to only 37% of loblolly trees being killed. Alpha pinene levels, a monoterpene which aides SPB aggregation, in Virginia pine are almost two times the amount in loblolly pine. Higher levels would increase attractiveness of Virginia pine (Veysey et al., 2003). Results from the study found that the SPB had completely altered the composition of the pine stand to virtually only loblolly pine. Friedenberg et al. (2007) posited that longleaf pine was more evolved with the SPB than loblolly pine. Their analysis of historical data revealed that SPB infestations were much more fatal and common in loblolly stands compared to longleaf.

Climate

Climatic disturbances help provide the feedbacks necessary for SPB population levels to pass thresholds limiting exponential growth. Lorio and Hodges (1968) determined oleoresin exudation pressure was poor where water stress occurred. Most importantly, they found that flooded trees experienced the highest risk for attack when considering moisture levels. In 2008, Friedenberg et al. posited that extreme cold temperatures reduce SPB survival and extreme warm temperatures disrupt emergence synchronization having significant effects on population levels.

According to Blanche et al. (1985b), lightning struck trees release attractants, decrease toxic monoterpenes, reduce total resin flow, and limit the relative water content in the bark, collectively making trees much more susceptible to SPB attack. Earlier research by Coulson et al. (1983) suggested that lighting strikes in the Southeast were the most and only consistent method of disturbance in the region. The phloem was found to have the highest conductivity. Severe wounds from superheating the phloem resulted in more SPB infestation due to lightning than wind and ice wounds (Coulson et al., 1983). A study by Hanula et al. (2002) regarding fire damage, concluded that trees with severe damage to the bole experienced higher mortality than those with damage to the crown. They also found that injuries to the stem from fire damage would seem similar in severity to lighting strikes, suggesting a high hazard for SPBs, but the association between SPBs and fire is not well understood.

Hedden and Billings (1979) described seasonal SPB activity: spring and fall spot establishment, and summer spot growth. The same study described moderate SPB population sizes as reliant on stand density, whereas large spots were dependent on SPB populations. Experiments aimed at enumerating the distance SPBs travel determined that 1/3 went further than one kilometer (Turchin and Thoeny, 1993). The beetles also traveled two times further in spring and fall compared to distances during the summer. Johnson and Coster (1978) examined aggregation success measured by distance from the infested host. They found attraction pheromones were much less effective at distances over 18ft, and inhibitor pheromones may only be useful in small populations with spaced out stands.

The microclimate around small groups of trees has dynamic effects on the behavior of SPBs (Schowalter et al., 1981). Female SPBs initiate attacks on suitable trees and begin colonization. They are also responsible for releasing frontalin, an aggregation pheromone, which concentrates populations to the targeted tree (Pureswaran et al., 2008). The ability for this bark beetle to aggregate is key to overpowering the natural defenses of pine trees.

Schowalter et al. (1981) indicated wind and temperature have profound effects on aggregation plumage and infestation enlargement under low population levels. They posited that stands with increased spacing and limited understory vegetation limit the effectiveness of plumage because warm temperatures and wind disperse the aggregates.

Tree Physiology

Tree resin, and the compounds contained in it, is the main defense mechanism for trees to combat SPB once they have landed onto a suitable host. Hain et al. (2011) suggested that a tree must be attacked by 5,000-15,000 beetles to create successful conditions for reproduction. Oleoresin exudation pressure (OEP) and relative water content (RWC) in the inner bark of loblolly pine trees have a strong relationship during water stress events (Lorio and Hodges, 1968). Flooded trees or highly water stressed trees increase the hazard for stands making them susceptible to damaging agents. Research by Bishir et al. (2004) determined that more beetles land on the bark of host trees than tunnel into the inner bark. The authors demonstrated that resin and predators play a role in reduced bark penetration and beetle mortality. More work is necessary to develop methods to prevent beetles from landing on host trees.

SPB Predators and Associates

The complex ecology of the SPB also has relationships with predators, competitors, and parasitoids. Fettig et al. (2007) suggested the most significant predator of SPB to be the checkered beetle (*Thanasimus dubius*, Fabricius). Hain et al. (2011) present many other predators of SPB and state that *T. dubius* is the most significant predator, but conclude that it is not an extremely efficient predator of SPB. *Ips* spp. can occasionally compete for hosts with SPB, but they tend to colonize different sections of tree boles (Hain et al., 2011).

Parasitoid research on SPB populations is ongoing, VanLaerhoven and Stephen (2008) attempted to determine if parasitoids would fail to prey on SPBs if honeydew was present on foliage. The results were limited in establishing significant relationships on the population dynamics of SPB. However, earlier research (VanLaerhoven et al., 2005) using Eliminade, an artificial insect food with dye, indicated that parasitoids favored the search for food over hosts. Continued research is necessary to determine the extent of influence of other insects on the population dynamics of the SPB.

SPB ecology is further complicated by the involvement of mites and fungi. Female SPBs have a mycangium in the pronotum that carries fungal spores. The female uses this space behind the head to store fungi until the beetle creates a gallery and inoculates the inner bark with fungal spores. The fungal spores develop into hyphal masses that provide nitrogen rich nutrients to developing SPB larvae (Pechanova et al., 2008). However, the SPB can also carry phoretic mites that do not directly affect the SPB, but do have negative indirect effects resulting from the spread of an antagonistic fungi carried by the mites that reduces the effectiveness of SPB reproduction (Hofstetter et al., 2006).

The mites are usually carried under the elytra of the SPB and contain harmful fungi like *Ophiostoma minus* (Hain et al., 2011). O. minus (blue stain fungi) can by itself kill trees by blocking phloem. The blue stain fungi compete with positive mycangial fungi, like *Entomocorticum* sp. A and *Ceratocypstiopsis ranaculosus*, which can severely limit larvae survival and development (Pechanova et al., 2008). The population dynamics of fungi and mites have profound effects on beetle reproduction rates. There are many complex factors that combine to produce substantial feedbacks and inputs governing the population dynamics of the SPB.

HISTORY AND MANAGEMENT

There may not have been catastrophic outbreaks in southern forests before Europeans settled in North America (Schowalter and Turchin, 1993). The efforts of Schowalter and Turchin (1993) put forth that the environment of the Southeast has fundamentally been altered and that the relative balance might be able to be restored by returning conditions to previous time: increasing the fire frequency, mixing hardwoods with pines, and replanting longleaf pine to dominate the landscape. Longleaf pine trees were harvested on wide scales for naval stores for ships in colonial times. Over time, European settlers failed to regenerate longleaf and began a regime of fire prevention. These changes have allowed loblolly pine and other SPB susceptible species to dominate the landscape in recent times. The relationships between the SPB, biotic, and abiotic factors are complex (Belanger et al., 1993). The findings from Belanger et al. (1993) indicated that stand age, season and the environment all played significant roles in determining the likelihood of host pines being infested by SPB. Their research promoted thinning stands, increasing regeneration through earlier harvests, and by converting forests to more resistant species.

Hedden (1978), Santoro et al. (2001), and Billings (1979) all argue that an additional factor that may have disturbed the environment was the use of insecticides until the late 1960s. It remains unclear how severe the relationships between predator, prey, and other members of the ecosystem were altered during this time. After insecticides, sanitation cuttings and other systems of disrupting the spread of SPB were advocated (Hertel and Wallace, 1983; Morris and Copony, 1974; Hodges and Thatcher, 1976; and Moser et al., 1997).

Morris and Copony (1974) found that wood around outbreaks that had salvage thinnings had less tree mortality than surrounding areas that were left standing unthinned. Hodges and Thatcher (1976) discovered a benefit to sanitation treatments when logs had direct sunlight, high temperatures, and were rolled over so that all sides were exposed reducing the likelihood of survival for beetles and the brood. Pine engraver beetles infest stressed pine trees and the larvae feed on the phloem, girdling trees and overwhelming their defenses. Recent results have found that SPB probably does not compete with other pine engraver beetles (*Ips* spp.) because they each attack different areas of the tree when standing or lying on the ground (Moser et al., 1997). SPB is found to generally attack the middle bole when standing, sides and bottom when the tree has fallen. However, *Ips* spp. were found to prefer higher portions of the bole and the top of fallen trees. Supporting the earlier sanitation studies, Moser et al. (1997) gathered that down trees may function as sinks for SPBs during hot weather.

Stand Spacing and Competition

Competition and spacing are key components of forest management. Wide spacing of loblolly pine trees has been tested to determine how growth speed and size react. Zahner and Whitmore (1960) described that the wider spaced stands had better soil moisture due to less root occupation from competition. Also, widely spaced stands had increased seasonal growth for five years until competition returned. The basal area remained higher in closer spacings, but the wide stands had large trees. In 1980, Lorio produced the first loblolly pine stocking chart in an attempt to improve at-risk, dense stands and found that SPB was unlikely to infest stands over 20-25ft in spacing.

After sanitation, stand modification to reduce hazard levels gained favor with techniques like thinning (Belanger et al, 1993; Nebeker and Hodges, 1985; Brown et al., 1987; Hedden, 1978; Lorio, 1980; Belanger et al., 1993; McNab, 1977; Ku et al., 1980; and Cameron and Billings, 1988). Thinning has been found to reduce competition, and improve tree vigor. Stands with high hazards for SPBs have been associated with the following characteristics: high basal area, low oleoresin exudation flow (Brown et al., 1987), low annual growth rate, disease, damage, old-growth (Turchin et al., 1999), high pine/ hardwood ratio, low site index, and acidic soils (Ku et al., 1980). There has been some success in killing off weakened trees, in effect, thinning pine stands with the use of low-intensity fires (McNab, 1977). Thinning should be conducted early by culling trees with poor form, disease, or bad health (Belanger et al., 1993). Brown et al. (1987) suggested that oleoresin exudation flow increased for at least two years after thinning trees resulting in healthier, more vigorous stands that were less susceptible to SPBs.

Oleoresin Defense

The main defense mechanism for pine trees to defend against SPB attack is oleoresin, which acts as a chemical barrier, due to the toxins, and a physical barrier preventing access to the inner bark of the tree (Veysey et al., 2003). Oleoresin can prevent oviposition and hinder the release of aggregation pheromones by SPBs. Trees with low resin weight have been shown to have the highest infestations (Boyle et al., 2004). The quantity of resin was linked to the percent of latewood present. It is believed that while early wood moves resin vertically, latewood can move mass quantities of resin horizontally in a tree thereby reducing mortality.

Different species of pine produce higher and more deadly flows of oleoresin compared to others. Shortleaf, Virginia, and loblolly pine are known to be more susceptible to SPB whereas longleaf is less (Belanger and Malac, 1980; Freidenberg et al., 2007; Veysey et al., 2003; and Ku et al., 1980). Loblolly is less likely to be infested compared to the previous two at-risk species as long as population levels are low and the tree is healthy. Slash pine is also more resistant to the SPB due to its viscous resin with long flow and lengthy crystallization rates (Cameron and Billings, 1988). However, except for native ranges, slash pine is not planted universally due to the low resistance to root rot. Management recommendations should always include planting the right species on the right site type (Nebeker and Hodges, 1985).

Stand Composition

Mixing hardwoods between pine monocultures can reduce the effectiveness of SPB aggregation pheromones and increase the distance between host trees (Belanger et al., 1993). Monocultures allow SPB populations to spread unchecked under the right conditions resulting in severe mortality (Cameron and Billings, 1988). Schowalter and Turchin (1993) emphasized that dense hardwood competition with pines does not make stands susceptible to SPB. The results of the study supported other research that mixed stands help prevent infestations. Nonetheless, even mixed stands may not be successful at preventing infestations when population levels are already high. Moser et al. (1997) also found that spot growth ended with spacing or the use of mixed hardwoods.

Even with the best planning, SPB can still infest pine stands. Disturbances act as facilitators, given the right pre-conditions, to provide increased opportunities for SPBs to attack trees with weakened defense systems allowing for population growth (Ku et al., 1980). Cameron and Billings (1988) reported that 53% of SPB outbreaks that were studied had evidence of disturbance at the initial site of spot growth. Since the SPB is able to take advantage of disturbed forests, many have postulated that naturally thinning poor trees is a niche that the insect has filled in the native ecosystem of the Southeast U.S. (Fettig et al., 2007; and Schowalter et al., 1981a).

Disturbance

Logging, lightning, wind, disease, flooding, insect, and fungal damage have all been linked to increasing stand hazard to SPBs (Belanger et al., 1993; Hedden, 1978; Nebeker and Hodges, 1983; and Nebeker and Hodges, 1985). Nebeker and Hodges (1983) revealed that logging damage to roots grows as proximity to the bole of a tree is increased. Also, logging during wet conditions has been shown to increase negative impacts on forest stands. Damage to the base of trees and roots can reduce growth rates which are known to raise the hazard for SPB and provide entrance pathways for pathogens like fungi to enter (Nebeker and Hodges, 1985).

There are many favorable management techniques suitable to reduce SPB populations. Solutions include reactionary and preventative concepts. Belanger et al. (1993) found that the focus of management should be on high hazard and high value stands. It is important for all landowners to recognize that management does not have to occur on a region wide scale in order for it to be effective (Hedden, 1978). Some management is better than no management, which is common for small landowners in the Southeast.

An important factor of management is a method of monitoring, such as the monthly spotting flights covered in Billings (1979). It is also critical to spread information to those who can make use of it, which Thatcher et al. (1982) was able to do by helping consolidate material about seasonal SPB activity and the appearances of different stages of spot growth. Payne and Richerson (1985) reported some success in utilizing pheromone inhibitors to prevent SPBs from benefitting from their aggregation pheromones. Government officials are also actively monitoring SPB population levels by using Lindgren funnel traps that are probably not effective at controlling populations, but do give an idea of presence or absence.

Many of the solutions listed above have been included in the Southern Pine Beetle Integrated Pest Management (IPM) Plan (Salom et al., 2004) which consists of six sections: prevention, predictions, detection, evaluation, infestation suppression, and area-wide suppression. The SPB IPM Plan is used to provide scientifically proven silvicultural recommendations for forest management to address SPB problems.

MODELING EFFORTS

With the increase in the ecology of the SPB and some of the underlying relationships of the insect, modeling efforts have been used to predict SPB populations. Research has taken many different courses over the past half century, but was initially focused on explaining the specific stand characteristics that favored SPB population growth. Modeling science has evolved to include different geographic scales, climate, stochastic risk, fire and stand dynamics over time, and very complex models utilizing knowledge of host species and the SPB. All modeling efforts are concerned with building and improving estimates of SPB populations so that management techniques can be adjusted and so that the behavior of this native pest is better understood in relation to its environment.

The definitions for hazard and risk associated in modeling will be used in conjunction with those explained by Fettig et al. (2007). *Hazard* is defined as the stand characteristics that influence host susceptibility. *Risk* is susceptibility combined with the actual presence of SPB populations on specific sites. These terms will be used throughout this discourse.

SPB Infestation and Management

Some of the earliest modeling attempts incorporated available stand data in predicting SPB spot infestation growth (Billings and Bryant, 1983; and Hicks et al., 1980). These efforts resulted from the forestry sector trying to prevent catastrophic population levels such as the ones that occurred in the 1970s causing extensive damage to Southeastern forestland owners. Researchers and land managers were able to understand that large regions were at risk due to favorable host type being in proximity to SPB populations.

Prediction models began to be used as management tools to undertake silvicultural treatments to reduce SPB hazards. The estimates created very cost effective risk ratings that required simple forest measurements and could be conducted at the lowest user level (Daniels et al., 1979; Lorio et al., 1982; Redmond and Nettleton, 1990; and Reed et al., 1981). Reed et al. (1982) built on early model estimates and added annual variation by weighting probabilities. Zhang and Zeide (1999) used a model that revealed stands with mixed hardwoods dispersed with pines had fewer attacks than pure pine stands. Stand characteristic models have been effective at helping forest managers determine what actions may increase or decrease SPB population growth. The majority of these models such as the one used by Leduc and Goelz (2010) are designed around growth and yield applications and SPB hazards, but they do not include economic data as outputs.

Scale Effects

Another distinct research field used by modelers is the concept of scale. Analysis of models is generally divided into three to five levels: spot and local levels, county and connected forests, and regional or large scales. Scale analysis reveals that different factors dominate at different scales. Mawby and Hain (1985) argued that population levels were the universally most important factor at all scales. However, recent research revealed that average climate conditions played a large role in predicting SPB population levels at the county level (Duehl et al., 2011). They (Mawby and Hain, 1985) also posited that large scale models should successfully be able to predict "the direction of change, the relative size of change, and the imminence of a large increase (p. 54)." Duehl et al. (2011) supplied a very detailed review of SPB modeling including a specific focus on scale analysis.

It is important to recognize that scale models work well in the setting in which they were constructed, but are constrained to those levels of analysis and cannot be applied universally. Reed et al. (1981) supported the emphasis of scale by arguing that a modeling approach focusing on the behavior of the insect itself creates a fairly good predictor for micro level analysis, whereas modeling forest stands provides a potentially good predictor for macro level estimates. Hedden (1985) experienced this problem using the CLEMBEETLE SPB spot simulation model when trying to expand the model into a regional tool.

The SPB is also influenced by the climate. Michaels (1984) combined historical precipitation and temperatures in Virginia and the Carolinas into an interactive computer program (SPBCOMP) that tried to predict large scale SPB outbreak severity. The results revealed that temperature and precipitation do have varying influences on SPB populations, but the relationships are very complex. Gan (2004) built on previous efforts and looked at possible future SPB risks associated with the effects of climate change. The models resulted in an overall increase in SPB infestation risks by 2.5-5%. It must be considered that the effects of climate change are poorly understood, but that minor changes could alter species distribution and historical winter temperature limitations to SPB population survival (Duehl et al., 2011).

Risk

A third branch of modeling research involves the incorporation of risk into traditional optimal management solutions. The efforts attempt to determine the best harvest schedules by including stochastic risks from the environment such as wildfire (Martell 1980) and wind (Thorsen and Helles 1998). Caulfield (1988) also used the risk of wildfire in modeling and found that optimal rotation ages were lower than those without wildfire risk. The author also found that the inclusion of risk provided forest owners additional choices when making management decisions. Pukkala (1998) utilized multiple risks and multiple objectives and found that over time, the risk preference with the lowest utility loss involved risk neutral forest owners compared to risk avoiders and risk seekers whom both fared the worst.

Stand Composition Simulations

Forest stand dynamics in relation to the SPB are another important field of modeling research. Fire regimes, species characteristics, time, and disturbances all play major roles in determining the distribution and composition of species on a landscape. SPB stand dynamics are dominated by two different simulation models: LANDIS a raster based model (Cairns et al., 2008a; Lafon et al., 2007; Waldron et al., 2007; and Cairns et al., 2008b), and the Forest Vegetation Simulator (FVS) (Coleman et al., 2008a; and Coleman et al., 2008b). The Forest Vegetation Simulator research was conducted in the Gulf States whereas the LANDIS research focused on the Southern Appalachian areas.

Xi et al. (2009) (and the other LANDIS articles listed above) found that without changes to fire suppression, Eastern White Pine and oaks will increase whereas Southern pines will die off in the mountainous regions of North Carolina and the Southern Appalachians. The LANDIS studies found that SPB and fire disturbances together tend to keep oak and pine populations in balance. When one of the disturbances are removed the dynamic changes and over time, and forest composition is altered. The FVS simulations concluded that weak disturbances resulted in a loss of pines and an increase in hardwoods.

All of the stand dynamic models emphasize the fact that planners and owners must consider the natural history of the land when developing policies and management strategies that have long lasting changes to the relationships of species in given ecosystems. These models fail to represent small scale situations well.

A new branch of modeling research was put forth by Bishir et al. (2009) regarding the daily interactions between loblolly pine and the SPB. The authors constructed a complex model called the Southern Pine Beetle and Loblolly Pine joint population dynamics model (SPBLOB), which attempts to reveal population dynamics of pest and host over the life of a stand. The program also has the capability of including climatic factors. The program does not function as an estimation tool, but rather a guide of the interactions involved in the population dynamics. Although it does not provide predictions, the program will prove useful in continuing to understand the many complexities of the SPB.

POLICY FRAMEWORK

"In 2002 President Bush proposed the Healthy Forests Initiative (HFI)… in an effort to restore ecosystems into healthy natural conditions…the south was recognized due to serious threats…from surges in nonnative and indigenous pests and diseases…outbreaks can inflict losses on individual owners and all forest owners (wood pricing) (Molnar et al., 2007, p. 93)."

The current strategy to combat the SPB is through education, monitoring, and sound silviculture and management techniques. Since the insect is native to the U.S., the strategy is not focused on eradication, but understanding how the SPB relates to its environment and how to prevent populations from swelling to catastrophic levels.

Earlier policy efforts focused on supporting suppression techniques. Clarke and Billings (2003) found in their analysis of SPB suppression on National Forests in Texas in the 1990s that efforts resulted in a 3.55 benefit/ cost ratio. The authors concluded that although suppression techniques were beneficial, the efforts were reactionary and do not address the fundamental changes needed to reduce SPB population levels before they reach destructive intensities. Perceptions were beginning to shift from a reactionary approach to a preventive one.

When considering policy strategies in the Southeast U.S., increasing fragmentation may be an important factor in managing for SPB (Molnar et al., 2003). They found that property in the Southeast is being increasingly broken up into smaller parcels, and found that population growth in the South is a major cause for the fragmentation. They also found that very few landowners actually took routine steps to care for the health of their forest. Numerous fragmented landowners with poorly managed forests can result in a high hazard and susceptibility for SPB infestation (Molnar et al., 2003).

Researchers have hypothesized several reasons why non-industrial private forestland (NIPF) owners make detrimental management decisions that make their property and surrounding properties vulnerable to SPBs. Mayfield et al. (2006) found that management decisions affecting SPB prevention varied between large and small forest owners. Conflicting management objectives or none, lack of awareness of threat, prohibitive cost, and lack of recent attack were the main arguments cited for the detrimental decision making. Larger forest owners were more likely to undertake proactive measures at preventing the SPB whereas there was a drop-off in prevention measures by forest owners of 50 acres and below (Molnar et al., 2003; Molnar et al., 2007; and Mayfield et al., 2006).

Southern Pine Beetle Prevention Program

Throughout 1999-2003, SPBs damaged close to a million acres of forest resulting in about $1 billion of financial loss (Nowak et al., 2008). Pye et al. (2011) constructed a thorough breakdown of how SPB outbreaks affect individual NIPF owners in regards to management decisions and the resulting economic impacts from those decisions. The authors also discussed the effect that salvage operations trigger to the state and region wide forestry sector. In 2001, the National Association of State Foresters provided a seven step framework recommendation in conjunction with the U.S. Forest Service in combating the SPB. Later in 2003, the Southern Group of State Foresters and the U.S. Forest Service created the Southern Pine Beetle Prevention and Restoration Program (SPBPRP). Funding for the program was provided by H. R. 1904 "The Healthy Forests Restoration Act of 2003," and eventually through the Southern Pine Beetle Initiative (H.R. 1904, 2003; Nowak et al., 2008; and Coulson and Meeker, 2011). The structure of the program was designed to be preemptive in philosophy instead of reactionary.

The SPBPRP has three specific objectives aimed at reducing damages caused by the SPB: a federally funded cost share program implemented by the 13 Southeastern states, educating the region on the potential threat and management solutions, and undertaking scientific research to refine solutions (Rossi et al., 2010). One aspect of the program is the creation of state SPB hazard maps. These maps assist government officials in determining at risk locations. Once the locations are known, the cost share program is administered by offering financial incentives to encourage forest owners to undertake supported silvicultural measures. The maps reveal hazard areas of susceptible forest composition and structure where the cost share program will have the biggest effect (FHTET, 2008). Supported treatment efforts include: precommercial thinning, prescribed burn, planting longleaf pine, and using wider spacing during planting. Interestingly, Thatcher et al. (1982) argued for a simple hazard mapping system, preventive silviculture, and education to combat the SPB twenty years before the SPBPRP was implemented.

Rossi et al. (2010) evaluated the SPBPRP through two NIPF owner surveys that provided near unanimous approval for the program. If given the opportunity, 99% of enrollees in the program responded that they would enroll again. These findings are supported by Bullard et al. (2002) and Cubbage et al. (2003) who mentioned NIPF owners were interested in public subsidies that could help in rates of return. The report (Rossi et al., 2010) found that survey participants learned and preferred printed material over educational workshops. Thinnings were the most common treatment method undertaken. Also, respondents had the highest interest in participating in the program due to being motivated to reduce risk of mortality. An added benefit to the program is that management participants are reducing SPB hazard, but also improving forest health and wildlife.

CAPITAL DECISION MAKING TOOLS

There are many tools useful for forest management decision making and analyses, here are a few: benefit cost ratio, internal rate of return, net present value, and soil expectation value (Cubbage et al., *In press*; Teeter, 2007; and Davis et al., 1987). Benefit cost ratio (B/C) is a ratio when total revenues and costs are discounted. A benefit cost ratio greater than one would be an investment that is preferred (Cubbage et al., *In press*). Internal rate of return (IRR) is the discount rate when discounted revenues equal the discounted costs. It is usually used to assess individual investments and an IRR above the minimum acceptable discount rate would be profitable. Both IRR and B/C ratio lack the ability to provide a monetary weight for decision making purposes (Teeter, 2007). Net present value is the discounted value of a future income flow. It is used to compare multiple investment opportunities with fixed discount rates and time horizons. These three capital budgeting criteria are all limited to fixed time horizons.

The Faustmann (1849) Model was developed to ascertain the optimal rotation method of various management options with different time horizons (Abt et al., 2003). This model is also known as soil expectation value (and land expectation value) because it provides an estimate for the value of land assuming forest rotations are grown with an infinite horizon. There are three choices when presented with SEVs: if an SEV is negative the IRR is less than the market discount rate, if the SEV is zero the discount rate is equal to the IRR, and if the SEV is positive the IRR is greater than the market discount rate.

The equation assumes: prices are static, the discount rate is representative of the landowner, the management regimes are consistent into perpetuity, all costs are included, no risk levels, stands begin with bare land, and even aged management is conducted with clearcuts (Davis et al., 1987; Abt et al., 2003; and Huang et al., 2005). The SEV model is widely used for monetary comparative purposes (Cubbage et al., *In press*). Abt et al. (2003) includes an excellent discussion of improvements to the Faustmann Model including those involving uncertainty.

Economics and the Southern Pine Beetle

Studies regarding the economic effects of the SPB are limited. The primary reason for this is the lack of available and relevant data to conduct analyses (Holmes, 1991). The best data set available is provided by Pye et al. (2008). The vast majority of SPB economic research has been focused at evaluating suppression activities (de Steiguer et al., 1987; Clark and Billings, 2003; and Redmond and Nettleton, 1990). Each of these studies used the benefit cost ratio as the economic assessment tool for analysis. In each case suppression activities were found to provide benefit cost ratios of three or better. Leuschner and Young (1978), also used the benefit cost ratio tool, but found that SPB damage had a considerable impact on the recreational values of campsites.

Holmes (1991) utilized a welfare effects analysis to show that SPB epidemics produced a negative net change in economic welfare. Gan (2003) estimated that damages from SPB due to climate change would result in losses of over $300 million in various climate scenarios. Burkhart et al. (1986) used net present value to conclude that thinning treatments could be expected to limit losses from SPB attack on average and better sites. Pye et al. (2011) portrayed the market effects of SPB during salvage situations.

CURRENT RESEARCH GAPS

A vast majority of current research of the SPB is involved in modeling and understanding the chemical components of attraction and dispersion. Additional efforts are needed in understanding predator and parasite relationships with SPBs. The effects of fire on the SPB have been somewhat conflicted and more work is necessary to provide clarity (Cameron and Billings, 1988; Sullivan, 2003; Santoro, 2001). Another issue that requires analysis is the conflicting policies of red cockaded woodpecker (*Picoides borealis*) (RCW) habitat preservation and SPB prevention (Nowak et al., 2008; Turchin et al., 1999; and Schowalter and Turchin, 1993). The RCW requires old growth habitat that is at odds with SPB objectives of harvesting pine trees that are declining in radial growth rates. Analysis is needed to determine how to meet the requirements of both policies simultaneously. Economic analyses are needed, but are limited by the availability of data.

The Southern Pine Beetle is a native pest that can cause substantial damage to forests of the Southeast U.S. It is an insect with a complex ecology that is not totally understood. Since the ecology is so complex, efforts at modeling SPB populations and the resulting tree mortality have been difficult. Significant strides have been made in developing silvicultural management strategies that inhibit SPB populations from reaching catastrophic levels. However, since the Southeast is dominated by small NIPF owners, a major obstacle remains in educating certain NIPF owners about the management options to prevent SPB outbreaks

(Rossi et al., 2010). The SPB Prevention Program attempts to address the education dilemmas and provide incentives for expensive SPB treatments.

DAMAGE AGENTS IN SWEDISH FORESTS

The author is participating in a partnership between the European Union and the United States. Through this partnership he has attended two universities in Scandinavia and one in the United States. Although this thesis topic is centered on a pest native to America, a background discussion of disturbances from Sweden follows to highlight some similarities and differences. The review of damage agents in Sweden was provided as a summary to help facilitate continued collaboration in forestry issues internationally. The Trans-Atlantic Master's Degree Program in Forest Resources is a joint partnership between the U.S. Department of Education, the E.U. Fund for the Improvement of Postsecondary Education (FIPSE), and by the EU – European Commission, Education, Audiovisual and Culture Executive Agency (EACEA).

Forests in Sweden, just as anywhere else, are slowly and constantly changing. It is difficult to specify how a forest should look unless one identifies specifically when and where (Nilsson et al., 2006). Today, Swedish forests are utilized as a multi-use resource. NIPF owners generally try to make a profit from their timber resource. The human impact of land use has created the most important form of disturbance today, whole stand harvesting (Widenfalk and Weslien, 2009). However, this has not always been the case. Pollen and charcoal sampling have been used to generate an idea of how Swedish lands have ebbed and flowed between different forest regimes (Bradshaw and Hannon, 1992; Bradshaw, 1993). Sweden's geography can be loosely characterized as having a nemoral zone, a boreal zone, and a mixing area or boreal-nemoral zone. Apart from human impacts, the forests of northern Europe are greatly influenced by disturbances such as fungi, browsing, insects, and climate and storms.

Human Disturbance

Bradshaw and Hannon (1992) conducted a pollen analysis on a forest located in East Central Sweden. The authors reported that 4000-2200 years ago, at this boreal-nemoral site, Sweden consisted of a mixed deciduous forest that was relatively open and had frequent fires. 2200-200 years ago, spruce (*Picea abies*) began to make a presence. Land during this time was characterized as open, while inhabitants utilized slash and burn techniques with a specific focus on cereal crops. In the last 200 years, fire has been suppressed and pine and spruce have dominated due to their fast growing nature. Fire cessation in southern Sweden has favored spruce, while climate change and browsing of ungulates have favored pine and spruce in northern Sweden both at the expense of deciduous species (Bradshaw, 1993).

Research conducted by Nilsson et al. (2006) on southern Sweden points out a similar result to Central Sweden (Nilsson et al., 2006). The authors note that around 0-500AD, human land use was concentrated on fertile coastal areas. It wasn't until a major deforestation occurred that man began to reside on the upland sites. During these points a semi pastoral lifestyle was adopted. Around 500AD, forests expanded and the human lifestyle land use diminished. Later from 1000-1400AD, agrarian land use grew at the expense of forests. Since the Middle Ages, humans in northern Europe have created dedicated family crop consumption areas (inmarken), and community grazing forestland (utmarken)(Nilsson et al., 2006). Deciduous forests in the utmarken continued to decline as populations grew and demand for land intensified. During this time (1558), King Gustav Vasa decreed that all beech and oaks were property of the crown because of their ability to provide pig fodder and for their use in shipbuilding. The result ended in a considerable loss in both due to unsustainable demand, and the unhappy peasantry who had giant trees in their fields (Nilsson et al., 2006).

In the past 150 years, frequent fires that were a part of slash and burn land use were reduced and conifers began to replace the deciduous forests of southern Sweden. Bradshaw (1993) points out that spruce is uniquely able to take advantage of a landscape with reduced large scale gap disturbances. Spruce trees are capable of filling individual gaps, whereas other common Swedish species such as birch and Scots pine require larger gaps to survive in the understory. Conifer monocultures have been favored for economic potential, but the homogenous forests have come at a cost to taxa that inhabited previous deciduous forests (Felton et al., 2010). In the future, disturbances and climate may make the site types currently dominated by conifers shift in favor of deciduous species once again.

Nilsson et al. (2006) noted that as you travel from north to south in Sweden the extinction rate of species grows. The reduction in fire and deciduous forest is a main culprit for many of the extinctions (Felton et al., 2010). Qinhong and Hytteborn (1991) assert that forest fire is the most common natural boreal forest disturbance. Forest rotations are generally shorter and coarse woody debris is less available for taxa that rely on it. Felton et al. (2010) note that varying fire severity provides niche species with preferred habitat that cannot be found elsewhere. By reducing fire, dependent species populations have dramatically declined. Olsson and Jonsson (2010) postulate that fire and deadwood are becoming important concepts that are being reintegrated into forestry practices in Sweden. However, adopting these land management principles may be beneficial to some species and costly to others. In a several thousand year chronosequence, Wardle et al. (2004) stated that a site in Sweden consisting of a northern island would physically lose shoreline if fire was suppressed, but would grow in square area if fire were allowed to occur. Disturbances were found to be critical to the ecosystem.

Fungi

In the right climactic conditions canker causing fungi such as *Grammeniella abietina* can become the biggest epidemic in Sweden (Wulff et al., 2006). These parasitic fungi can significantly damage, devalue, and kill Swedish conifers. During the mid-20th Century, Swedish forest owners planted lodgepole pine (*Pinus contorta*) from North America because of its growth characteristics. Early testing seemed to confirm that it would be more successful than the native *Pinus sylvestris*. The species was highly promoted. However, in the late 1980s researchers began to realize that certain provenances were poorly suited to coping with native parasitic fungi. In fact, only 24% of Scots pine forests were infected compared to 54% of lodgepole pine. Karlman et al. (1994) found that the high damage rates from the fungus were caused by several reasons: elevated areas, northerly slopes, depressions, and the year 1987 was the coldest summer on record. Fungi thrive in cool wet situations which is exactly what occurred allowing the fungus to grow and spread beneath the snow layer. Additionally, continental provenances that were planted were ill suited to the oceanic influence of Sweden (Karlman et al., 1994).

Ungulates

The nemoral and boreal climates are cool and have a different photoperiod compared to the tropics. The photoperiod and climate favor a boom and bust cycle for a majority of the flora native in Swedish forests. Ungulates such as the moose (*Alces alces*) and several deer species are forced to browse forest cover when more palatable resources are unavailable in the winter months due to snow and ice cover (Cassing et al., 2006). Browsing can cause substantial damage to forests. In 1982, 37% of pine stands in Sweden were severely damaged (Hörnberg, 2001). The moose population no longer has any prominent predation, so it is regulated in Sweden through legalized harvests or hunting. Moose levels fluctuate depending on many factors, but forest damage was found to be indicative of moose population levels (Hörnberg, 2001). Cassing et al. (2006) found that preferred species were browsed first and as a result were less common in Sweden.

Spruce Bark Beetle

The spruce bark beetle (SBB) (*Ips typographus*) is the biggest biotic risk to spruce trees in Sweden (Seidl et al., 2008). From 1850-2000, 8% of all forest damage was due to the SBB (Jönsson et al., 2007). The native insect tries to match its population to the susceptible population of its host. SBB does not commonly kill trees by itself. It generally prefers to colonize weakened or recently dead trees from drought, fire, storm, fungus, or other impact. It needs larger trees with suitable space to create galleries for eggs. Mature forests with a decline in tree vigor are potential havens for outbreaks (Jönsson et al., 2007). Fifty percent of gaps created by Hurricane Gudrun in 2005 were colonized the first summer, whereas 97 percent were colonized by the second summer (Schroeder, 2010). Schroeder (2010) found that the number of storm felled spruce was unrelated to the percent of spruce bark beetles colonizing in the 1st summer of an outbreak. In earlier work, Schroeder (2007) uncovered peak colonization of the pest to occur during year two and to taper off in years four and five.

Climate plays a major role in preventing the insect from being able to take advantage of large host material. Many sources note that SBB populations are highly dependent on the cumulative temperature sums which have been used in several SBB population modeling experiments (Jönsson et al., 2007; Jönsson et al., 2009). Latitude, photoperiod, and elevation are major factors that effect voltinism (Karlman et al., 1994; Jönsson et al., 2007). In central Europe, conditions generally allow for two generations of SBB, whereas in northern Europe a single generation can only develop due to the low cumulative temperature sums restricting further brood development. Climate modeling has shown that an increase in generations and swarming activity may develop, but after initial damages the host will be less suited in current ranges (Jönsson et al., 2007). The Southern and Central Swedish regions are most likely to see increases in SBB (Jönsson et al., 2009). Additional research is necessary to refine models and produce more accurate and useful prediction tools.

The SBB has many predators: other beetles such as *Thanisimius formicus*, parasitic wasps, woodpeckers, and flies (Wermelinger, 2004). Unmanaged stands were found to have higher SBB predator levels than managed stands (Weslien and Schroeder, 1999). However, Nordlander et al. (2003) pointed out that predator populations and locations generally took an entire generation to respond to SBB populations. Wegensteiner and Weiser (1995) found that 0.3-1.1% of SBB were infected with a virus located in vacuoles in the gut. There is limited knowledge on this aspect of the ecology of the beetle, and more is needed. Wermelinger (2004) provides a good background review of the ecology of SBB.

Other Pests and Damages

Swedish forests are also susceptible to damage from other insects including *Tomicus piniperda* (the pine shoot beetle) and *Hylobius abietis* (the pine weevil). The pine shoot beetle predominantly colonizes dead and dying trees. Even though the beetle can tolerate host defenses and often carries host antagonistic fungi, the beetle is not considered a tree killer because it lacks aggregation pheromones which are typical of tree killing beetles (Cedervind et al., 2003). Sikström et al. (2005) noted that Scots-pine with over 90% crown transparency had a high risk of mortality and damage from pine shoot beetles. Stressed trees with low growth rates, small diameters, and suppressed trees were found to be colonized the most. The beetle damages trees by feeding on shoots that result in stunted growth, and by introducing blue stain fungi (Cedervind et al., 2003).

The pine weevil can cause significant damage to clear-cut areas that are replanted with seedlings (Nordlander et al., 2003). The insect can slow the growth of trees and cause disfiguring damage. Shelterwoods have been shown to reduce the damage. Nordlander et al.

(2003) discovered that solar radiation levels played a role in feeding sites and that pine weevils often preferred the center of newly established forests. Sites with preserved vegetation provided more healthy roots for the pine weevils to feed on. Wallertz et al. (2006) postulated that shelterwoods had less damage to seedlings because there were more food sources available and the below ground options provided protection from predators and the environment.

Snow and wind cause $150 million in damages in Sweden annually (Valinger and Fridman, 1999). In 2005, the storm Gudrun caused 5.8 million tons of carbon loss in a single weather event compared to Sweden's annual carbon sink capacity of 14 million tons. It was the single most extensive damage on record (Blennow et al., 2010; Shroeder, 2010). Felled trees add carbon to a forest, but reduce a forests capability of acting as a sink due to their lack of respiration from mortality (Lindroth et al., 2009). Storm events result in unscheduled thinnings, additional insect and fungal damage, as well as eventual mortality. Qinhong and Hytteborn (1991) conducted a study finding relationships between the type of damage a tree received and the species. Pine, birch, and aspen all had a high percentage of dead standing snapped off stems, whereas spruce had a higher percentage of uprooted trees.

Blennow et al. (2010) describe that the susceptibility of species to damages from wind follows a gradient from low to high respectively consisting of birch, pine, and spruce. Valinger and Pettersson (1996) determined that thinned stands are more likely to experience wind damage and low thinned stands are likely to encounter snow damage. Also, dominant trees are most likely to be damaged by storm and weather events. The authors expressed that wind damage is generally due to stand characteristics, whereas snow damage typically results from site characteristics. Blennow et al. (2010) elaborated this point clarifying that new forest management can adjust the susceptibility of forests to wind damage. Through climate simulations, it was determined that higher wind damage was a result of a change in wind patterns no longer from the southwest, but now from the northwest (Blennow et al., 2010). Valinger and Fridman (1999) discovered in their climate modeling that central and western Sweden was predicted to be at a high risk to future damages. In recent climate modeling, southern Swedish forests with a presence of spruce and beech are expected to see a shift in favor of beech at the expense of spruce (Bolte et al., 2010).

METHODS

This research is trying to answer the question of whether the SPB Prevention Program's recommended thinning treatments are economically justifiable given the risk of SPB attack. Growth and yield simulations were produced for representative stands in the Southeast U.S. Estimates of risk of mortality, cost of treatments, and returns from preventing loss were modeled using the stand developmental reports from the growth and yield simulations. Risk adjusted soil expectation values (SEVs) were used to draw conclusions on the optimal rotation and assumed typical stand rotations for each stand. Non-industrial private forestlands (NIPFs) are the only ownership types examined in this study to limit the scope and to mirror the guidelines of the SPB Prevention Program (Nowak et al., 2008).

- H_0: Treatments sponsored by the SPB Prevention Program will not result in higher risk adjusted SEVs compared to control treatments.

STAND GROWTH AND YIELD SIMULATION

Throughout this study, 868 simulations were generated to represent a broad spectrum of typical forest stand conditions throughout the southeast U.S. Variables used to represent the myriad of factors affecting forests in the region include: physiographic region, species, stand origin, site index, and planting density. Treatments included: a control where no thinning was conducted, pre-commercial thins, and first thins. Stand simulations were conducted using the Simulator for Managed Stands 2009 (SiMS) (ForesTech International, LLC, 2009). The software utilizes numerous different growth and yield equations to simulate forest change over time.

The growth and yield of 252 natural and 616 planted stands were simulated to represent a range of stand conditions: regeneration method, site index, species, and physiographic region. When the 13 states of the Southeast (Alabama, Arkansas, Florida, Georgia, Louisiana, Kentucky, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia) are added, the simulations are identical for states that have the same physiographic regions resulting in 3,608 planted stands and 1,476 natural stands. The results of the simulations created stand development reports for each stand across time. The development report lists products (topwood, pulpwood, chip-n-saw, and saw-timber) in green tons from ages of 0 to 50 for planted stands and ages 0 to 80 for natural stands.

A variety of factors were used with several levels to represent stand conditions across the regions. Physiographic regions used in this study and supported by SiMS were Upper Coastal Plain, Lower Coastal Plain, Piedmont, West Gulf Coastal Plain, and East Texas. The Piedmont region covers the mountains. The software was created and designed for active stand managers. Slash and loblolly pine forests were used during this study where regionally appropriate and supported by SiMS similar to work by Cubbage et al. (2000) and Pye et al. (1997). Two separate stand origin scenarios were modeled: natural and planted . The planted stands had site indices of 55 ft, 70 ft, and 85 ft with a base age of 25 years. The seedlings used in the plantation simulations were all assumed to be 1.5x genetically improved, bare root, and hand planted. Natural stands had site indices of 70 ft, 85 ft, and 100 ft with a base age of 50 years.

Site indices for planted and natural stands were chosen based off of assessments from previous research (Burkhart et al., 1986; Snider and Cubbage, 2006, Pye et al., 1997; Cubbage et al., 2000; and Huang et al., 2005). Planting densities for planted stands were 500 trees per acre (TPA), 750 TPA, and 1000 TPA. Natural Stands were simulated to have initial densities of 1000 TPA, 1500 TPA, and 2000 TPA. These options were selected after reviewing previous research (Amateis and Burkhart, 2012; Anton-Fernandez et al., 2011; Davis et al., 1987; Snider and Cubbage, 2006; Pye et al., 1997; and Cubbage et al., 2000)

Three treatments were incorporated across the simulations. Control treatments included fixed assumptions, but no thinning regimes. The pre-commercial thinning (PCT) treatment, or thinning when products generated from the thin occur at early ages therefore result in a cost for a landowner, have ages 4, 6, or 8 (Davis et al., 1987; and Dubose et al., 2003). PCTs were included as treatments based off of NIPF participation through the SPB Prevention Program (Rossi et al., 2010; Nowak et al., 2008). It also has two thinning densities for the PCT to a level of 400 TPA or 550 TPA.

The third treatment, 1st thinning, has commercial thins at ages 12, 14, or 16 for planted stands to densities of 400 TPA or 550 TPA. Natural stands have 1st thins at ages 15, 20, or 25 to a density of 550 TPA. Ages for treatments were based on the goal of the SPB Prevention Program which was to encourage NIPF owners to thin stands during the ages where markets do not support treatments, such as pre-commercial thins and 1st thinnings of pulpwood (Nowak et al., 2008). Burkhart et al. (1986) and Cubbage et al. (2007) were also used as guidelines for establishing treatment age structures.

Only one type of thinning treatment was used per stand. The regimes were created to be representative of the type of stands that are present across the Southeast. Tables 1 and 2 show the number of simulations by treatment for planted (Table 1) and natural (Table 2) stands, respectively. The numbers of treatments are not exactly the same for the planted stands because of treatment limitations: some stands at 16 years of age did not have 550 TPA so that treatment could not be conducted, and simulations that started with a 500 TPA planting density precluded the use of any treatments where the thinning density was set to 550 TPA.

Table 1. Number of Simulations by Treatment for Planted Stands

Treatment	n	Percent of Treatments
Control	369	10.23%
PCT Age 4 to 400 TPA	369	10.23%
PCT Age 4 to 550 TPA	246	6.82%
PCT Age 6 to 400 TPA	369	10.23%
PCT Age 6 to 550 TPA	246	6.82%
PCT Age 8 to 400 TPA	369	10.23%
PCT Age 8 to 550 TPA	246	6.82%
Thin Age 12 to 400 TPA	308	8.54%
Thin Age 12 to 550 TPA	230	6.37%
Thin Age 14 to 400 TPA	273	7.57%
Thin Age 14 to 550 TPA	191	5.29%
Thin Age 16 to 400 TPA	246	6.82%
Thin Age 16 to 550 TPA	146	4.05%
Total	3608	100.00%

Note: PCT= pre-commercial thin; TPA= trees per acre

Table 2. Number of Simulations by Treatment for Natural Stands

Treatment	n	Percent of Treatments
Control	369	25.00%
Thin Age15 to 550 TPA	369	25.00%
Thin Age 20 to 550 TPA	369	25.00%
Thin Age 25 to 550 TPA	369	25.00%
Total	1476	100.00%

Note: TPA= trees per acre

The base growth and yield program assumptions in SiMS were kept constant across all regimes. Pulpwood specifications are stated as being from 4.5 inches to 8.5 inches diameter at breast height (DBH). Chip-n-saw class is stated as being from 8.5 in to 11.5 in DBH. The sawtimber merchantable class ranges from 11.5 in to 40 in DBH. Weight factors and allocation tables were generic from original program settings. The commercial thinning method used throughout was 5th row with selection. Soil management groups and herbaceous competition were listed as unknown and used default values as well. Woody competition was set at a low level, listed as light woody or 2%.

The SiMS stand development reports were exported individually to Microsoft Excel. The stands were then combined into a comma delimited file in the Python programming language. This step was needed to assimilate all of the natural and planted stands into single data sets that would ease continued analysis. SAS 9.2 Software (SAS Institute Inc., 2008) was used extensively in this study.

CALCULATION OF RISK ADJUSTED SOIL EXPECTATION VALUE

Pricing for different stand products were obtained from data published by Timber Mart-South (TMS) from current (4th Quarter, 2011) Southeast wide regional pricing reports for pulpwood ($8.20/ green ton), chip-n-saw ($14.26/ green ton), and saw-timber ($23.54/ green ton) (Siry et al., 2011). This timeframe was used to show results under current market conditions. Although data for the SPB was only available until 2004, the 2011 prices were chosen because biological factors change relatively slower than market trends. Product prices from 2005 were also included for comparison purposes from TMS: pulpwood ($7.10/ green ton), chip n saw ($23.90/ green ton), and saw timber ($39.53/ green ton) (Baldwin and Johnson, 2005). Sensitivity analyses were conducted to determine the effect prices had on parameter estimates. If 2005 prices were used throughout, SEVs would be higher and there would be larger differences between productive and unproductive stands. The topwood (small tops of trees) volume was set at 50% of the total topwood volume and included as pulpwood. All prices reflect averages using stumpage values.

SPB risk of tree mortality by state (Table 3) was derived from data by Pye et al. (2008). The time period where data was available was broadly the late 1970s through the early 2000s. State specific historic SPB damage and timber product market figures were used to create SPB risk of mortality mean averages by state. Data for Kentucky was limited. Outbreaks did occur in Kentucky, however data was not available to construct a SPB risk rate in the same manner as the other states (Pye et al., 2011; and Nowak et al., 2008). Inventory data from the USFS was available, but damage data was only available for two years. Additionally, the damage data for Kentucky occurred at a time span different from all other data available for the 12 other states in the region. Since the available data during timespans similar to all other states resulted in a zero SPB risk rating for Kentucky, an alternate risk was substituted using the next lowest risk rate from Arkansas. Mississippi and Oklahoma were completely missing the necessary data so the overall average of all 13 states was used since the actual risk was unknown.

Table 3. SPB Risk of Tree Mortality by State

State	SPB Risk of Tree Mortality	Years Data Covered By Data
AL	0.0035776	1982-2004
AR	0.0003259	1978-2004
FL	0.005916	1980-2004
GA	0.0033652	1982-2004
KY	0.0003259	1975-2004
LA	0.0055143	1984-2004
MS	0.004945	Missing Data
NC	0.0012095	1984-2004
OK	0.004945	Missing Data
SC	0.0062296	1978-2004
TN	0.025216	1980-2004
TX	0.0009632	1986-2004
VA	0.0010095	1984-2004

Establishment costs and thinning costs were provided through the experience and consultation of the collaborators of this study after reviewing literature (Cubbage et al., 2007; Abt et al., 2003; Redmond and Nettleton, 1990; Davis et al., 1987; Cubbage et al., 2003; and Dubose et al., 2003). The 2010 prices listed in Forest Landowner (Barlow and Dubois, 2011) differed from those used in this research for some treatments, but since all costs were held constant across regions and states, there should be little sensitivity to small changes in assumed costs. The main difference was that the assumed PCT cost was lower than what was used in this research. This would have an impact on the NPV and SEV for stands where PCT was used and could change management recommendations. The costs used in this research were made to be representative of costs across the south and cost estimates will vary depending on sample size and geographic location. PCT costs were set at $120 per acre. Establishment costs are listed in Tables 4 & 5 on a per acre basis. Total cost, in Tables 4 & 5, is the establishment costs for their respective region and planting density.

Table 4. Planted Stands Establishment Costs

Planting Density (TPA)	Seed Cost ($/ ac)	Planting Cost ($/ ac)	Chemical Site Prep ($/ ac)	**Total Cost ($/ac)**
Plantation Establishment Costs: Upper Coastal Plain, Lower Coastal Plain, West Gulf Coastal Plain				
500	25	60	85	**$170.00**
750	37.5	65	85	**$187.50**
1000	50	70	85	**$205.00**
Plantation Establishment Costs: Piedmont and East Texas				
500	25	65	95	**$185.00**
750	37.5	70	95	**$202.50**
1000	50	75	95	**$220.00**

Note: TPA= trees per acre; ac= acres

Table 5. Natural Stands Establishment Costs

Initial Density (TPA)	Chemical Site Prep ($/ ac)	**Total Cost ($/ ac)**
Natural Establishment Costs: Upper Coastal Plain, Lower Coastal Plain, West Gulf Coastal Plain		
1000	85	**$85.00**
1500	85	**$85.00**
2000	85	**$85.00**
Natural Establishment Costs: Piedmont and East Texas		
1000	95	**$95.00**
1500	95	**$95.00**
2000	95	**$95.00**

Note: TPA= trees per acre; ac= acres

Potential revenue for each stand at each year throughout the stand development was calculated assuming the stand was harvested. Total net present value was calculated with two revenue sources: the net present value for a specific stand in a specific year, and the net present value earned from a possible thin during the same year. A discount rate of 6% was used throughout this research unless otherwise noted. The rate was chosen after referencing previous literature (de Steiguer, 1987; Cubbage et al., *In press*; Cubbage et al., 2007; Abt and Prestemon, 2003; Cubbage et al., 2000; Chang et al., 2012; Snider and Cubbage, 2006; Redmond and Nettleton, 1990; Bullard et al., 2002; Atmadja and Sills, 2009; Burkhart et al., 1986; and Pye et al., 2011). A 4% discount rate is used very often in forestry (Cubbage et al., *In press*). Discount rates varied from 2% to as much as 15% (Cubbage et al., *In press*). For comparison purposes, a discount rate of 4%, was used in sensitivity analyses to ascertain the effect different discount rates had on the parameter estimates. Sensitivity analyses are useful in clarifying the effect of treatments on a management regime when the discount rates are unknown (Teeter, 2007; and Cubbage et al., *In press*).

The soil expectation value (SEV) was chosen as a comparative value because it can give the worth of a forest stand for an indefinite amount of time. This study assumes that NIPF owners already own their land and intend to keep it producing timber into perpetuity. Pye et al. (1997) and Cubbage et al. (2000) utilized SEV as an analysis tool in a similar risk and no risk scenario. SEV is the best capital budgeting criteria to use in this study because the time horizons vary between management options, and effects in dollar terms are desired. (Net present value (Eq. 1) is calculated because it nests as an input of SEV (Eq. 2). Both NPV and SEV were calculated on a per acre basis throughout this research.

$$NPV = \Big(\Big(\big(R * EXP(-i * a)\big) + \Big(R_t * EXP\big(-i * (a_c)\big)\Big)\Big) - \Big(\big(C_e\big) + \Big(C_t * EXP\big(-i * (a_c)\big)\Big)\Big)\Big) \tag{1}$$

Where

NPV= net present value
R= revenue
i= discount rate
a= age
R_t= revenue from the thin
a_c= age that thin treatment occurs
C_e= establishment costs
C_t= thinning treatment costs

$$SEV = \left(\frac{NPV}{\Big(\big(1 - EXP(i * a)\big)\Big)}\right) \tag{2}$$

Where

SEV= soil expectation value

RISK OF SPB ATTACK

The model used in this study to determine the risk of SPB was adapted from Daniels et al. (1979). The authors from the Daniels study, used a logistic probability model to estimate the probability of SPB outbreak in a forest stand in relation to the basal area of a stand and the proportion of pine in a stand. Several years later, Reed et al. (1982) improved the original model by including an annual weighting system that boosted the predictive value of the model. The design from this study incorporates the work from these two articles as well as the general format of Burkhart et al. (1986). In Equation 3, P_{D_k} represents the risk of tree mortality due to SPB attack when a stand increases in basal area. Basal area per acre (BA_{acre}) was provided by the SiMS growth and yield simulations, and the proportion of pine was fixed at 80% for this analysis just as Reed et al. (1982).

$$P_{D_k} = \left(\frac{1}{1 + EXP\left(4.829 - \left(0.0519 * \left(\frac{BA_{acre}}{4.356}\right)\right) - \left(4.062 * (\%\ PSC)\right)\right)} \right) \tag{3}$$

Where

P_{D_k} = Daniels et al. probability killed

BA_{acre} = basal area per acre

$\%\ PSC$ = percent pine species composition

This allows the risk of SPB attack to change annually for each stand, as the basal area per acre changes. According to Daniels et al. (1978), P_{D_k} is the 'unweighted' risk, which would be applied to a field survey where there was one infested stand for every uninfested stand included, which means that the unweighted values are high. To adapt this basal area dependent risk measure for this research, an index from the Daniels value was created such that the average for each stand for all ages would approximate the statewide average in Table 3. Thus, Equation 4 shows the adjustment to create an index for each stand and age.

$$P_K = P_{D_k} * \frac{P_S}{\bar{P}_D} \tag{4}$$

Where

P_K= probability of mortality from SPB

P_S= statewide SPB risk

P_{D_k}= Daniels probability

$\bar{P}_D$= average Daniels probability for the stand

The resulting probability increases as the stand ages and becomes more suitable to SPB populations. It is assumed that stands under age 8 did not provide suitable galleries for SPB larval development (Cameron and Billings, 1988). Figure 1 shows what the final SPB risk probability looks like for a single example stand. The probability begins at age 8 until it reaches a plateau caused by the naturally slower growth as the pine trees age.

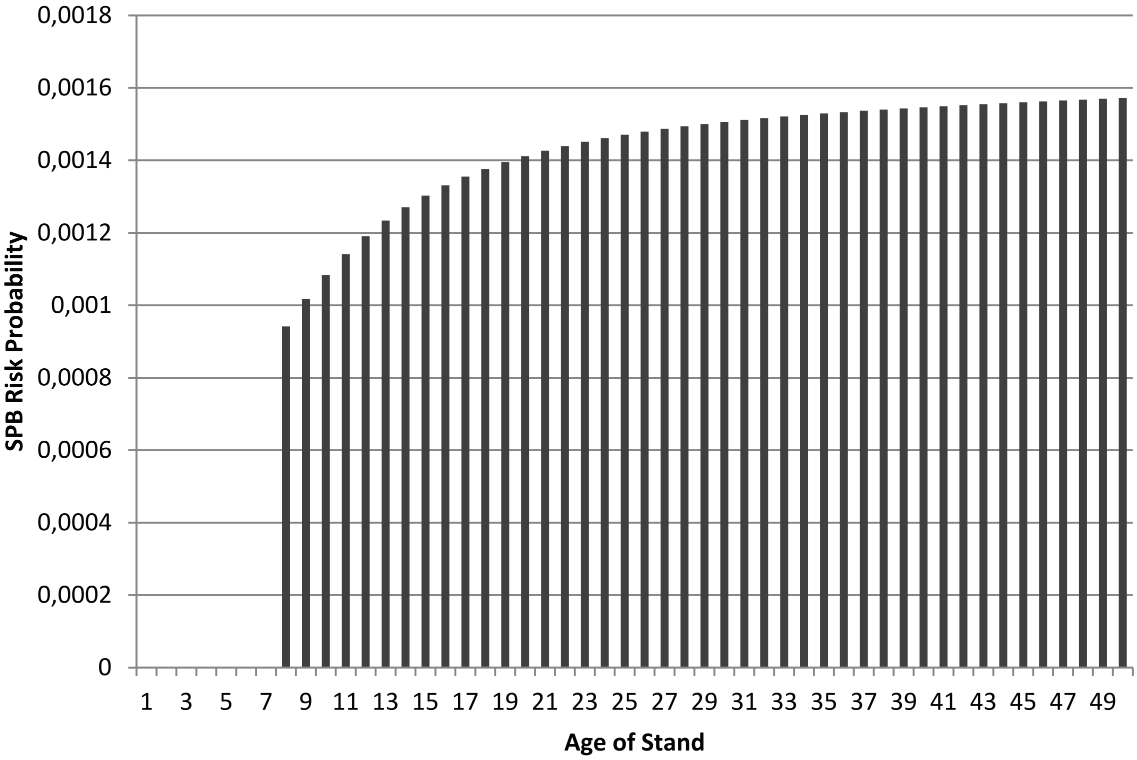

Figure 1. Individual Stand SPB Risk by Age (Planted Stand, NC, Piedmont, SI 85, Planting Density 1000TPA, Loblolly pine, Control Treatment)

RISK ADJUSTED SOIL EXPECTATION VALUE

Martell (1980) calculated a risk adjusted SEV, which was modified to include revenues and costs from thinning. In the Martell (1980) study, the risk of fire was incorporated to assess the impact on optimal stand harvest age. In this study, the stochasticity of SPB risk is used in place of fire. The probability is necessary in order to account for the increase in SPB mortality hazard as a stand ages and after every subsequent year that an outbreak has not occurred.

Also of importance from Martell (1980) is the concept of a catastrophic disturbance event that results in salvage operations and a resetting of the stand to age zero. This study incorporates a similar function, but assumes that if there is a catastrophic disturbance a salvage operation occurs. Under this assumption, salvage revenue is calculated annually using the available products from the growth and yield simulations. It was assumed that the combination of the damage to wood quantity and wood quality would reduce the total salvage value by 90% from the original potential harvest value when a SPB outbreak occurs. The economic values of the stands are calculated annually. In effect, every year has a salvage scenario and the optimal occurrence of SEV for each specific stand is produced. When the risk probabilities are removed from Martell's equation, the formula that results is for SEV. Martell's (1980) equation is made up of two components

$$E\left(\alpha \middle| P_K, k\right) = \left(1 - \sum_{i=1}^{k} P_j\right)\alpha^k + \sum_{i=1}^{k} \alpha^j P_j \tag{5}$$

Where

P_K = the probability that a stand will die from SPB in a given year (from Eq. 4)
k = the age of the stand
α = the discount factor (1+discount rate)^-t
j = the age of the stand at the year a catastrophic SPB attack occurs

$$E\left(R \middle| P_K, k, S\right) = \left(1 - \sum_{i=1}^{k} P_j\right)\alpha^k R_k + \sum_{i=1}^{k} \alpha^j S_j P_j \tag{6}$$

Where

R = the net revenue received in a given year
P_K = the probability that a stand will die from SPB in a given year (from Eq. 4)
k = the age of the stand
S = net revenue received if stand is theoretically damaged and salvaged in a given year (revenues at age k *10%)
α = the discount factor (1+discount rate)^- k
j = the age of the stand at the year a catastrophic SPB attack occurs

Martell (1980) does not include any thinning regimes in his model. This study has several thinning treatments and so additional parameters were created to represent the thinning revenue and cost. Thinning revenue (TR) is calculated as

$$TR = \left(R_t * EXP(-i * a_c)\right) \tag{7}$$

Where

$R_{t=}$ revenue from a thinning operation
$i =$ the discount rate
$a_c =$ age that thin treatment occurs

And is added to R in equation 6.

Thinning cost (TC) is calculated as

$$TC = C_t * EXP(-i * a_c)) \tag{8}$$

Where

$C_t =$ cost from a thinning operation
$i =$ the discount rate
$a_c =$ age that thin treatment occurs

And is added to C in Martell's (1980) full equation

$$f = \max_{k=1,2,3,...} \left\{ \frac{E_6\left(R \middle| P_K, k, S\right) - C}{1 - E_5\left(\alpha \middle| P_K, k\right)} \right\} \tag{9}$$

Where

$R =$ the net revenue received in a given year (including any thinning revenues)
$P_K =$ the probability that a stand will die from SPB in a given year (from Eq. 4)
$k =$ the age of the stand
$S =$ net revenue received if stand is theoretically damaged and salvaged in a given year (revenues at age k *10%)
$C =$ all costs (the cost of establishing the stand, and any thinning costs)
$\alpha =$ the discount factor (1+discount rate)^-k
$f =$ single max risk adjusted SEV for a stand

In summary, the state specific risks were taken from Table 3 and applied to the physiographic regions applicable within each respective state. These figures created a specific risk for each state called SPBRISK. The final equation incorporates several factors to develop a SEV adjusted based off of risks: risk from historic SPB damages, risk due to an increased basal area, and increased risk due to cumulative absence of damage to a stand by SPB.

The risk adjusted SEV was compared to SEV at age 35 for planted stands and age 45 for natural stands to simulate an assumed typical age that NIPF owners would harvest their stands throughout the regions, and to have a common point of reference (Burkhart et al., 1986; Cubbage et al., 2000; Pye et al., 1997; Cubbage et al., 2007). The results were compared to the ages where risk adjusted SEV and SEV were at their respective optimal per stand. These maximum levels are considered the optimal harvest rotation. It should be stated that this project predominantly relied on data generated from a growth and yield modeling system (SiMS). Because a model generated the data that is being analyzed, and the variables in the model were selected, it follows that the regressions and other statistical analyses should be significant. The expected fit is high and caution should be used in interpreting the significance levels because these tests may not have sufficient variation. There may also be other variables involved in nature that is unaccounted for in this model. The high R-squared values mean that the variation in the data form the growth and yield model is captured by the models. Because many factors were held constant, the only variables allowed to vary should naturally explain the differences found in the results of the data analysis.

The results were analyzed using a variety of statistical procedures in SAS 9.2 (SAS Institute, 2008). ANOVAs, T-tests and linear regressions returned high significance values which warrants the previously mentioned caution in using this model as a predictor. But, the results do give insight into the impact of certain treatments on the economics of SPB risks. Linear regressions were run to produce parameter estimates for the effect of variables on the change in risk adjusted SEV.

Table 6 explains the variable breakdown for the scenarios analyzed and subsequent linear regressions. States, physiographic region, species, PCT Treatment, and 1st Thin Treatment were used as dummy variables in the appropriate stands. The dummy variables were used to measure the difference across each variable. Site index, initial density, density of treatments, and age of treatments were used as continuous variables. The continuous variables allowed context regarding how much change in SEV occurred with an increase in each level.

Table 7 portrays the 16 different linear regressions that were run for the sensitivity analysis between product prices and discount rates. Alabama, loblolly pine, and East Texas were used as a baseline scenario. This scenario was arbitrarily chosen. The parameter estimates from the regressions, and the change in the estimates provides understanding on the influence that the parameters have on the results.

Table 6. Variables Used in Linear Regressions

Variable	Type of Variable	Stand Application	Intercept	Number of Levels
State	Dummy	Planted & Natural	Alabama	12 (+1 intercept)
Physiographic Region	Dummy	Planted & Natural	East Texas	4 (+1 intercept)
Species	Dummy	Planted & Natural	Loblolly pine	1(+1 intercept)
Site Index	Continuous	Planted & Natural	NA	3
Initial Density	Continuous	Planted & Natural	NA	3
PCT Treatment	Dummy	Planted	Control Treatment	1 (+1 intercept)
1st Thin Treatment	Dummy	Planted & Natural	Control Treatment	1 (+1 intercept)
Age of PCT Treatment	Continuous	Planted	NA	3
Density of PCT Treatment	Continuous	Planted	NA	3
Age of 1st Thin Treatment	Continuous	Planted & Natural	NA	3
Density of 1st Thin Treatment	Continuous	Planted	NA	3

Note: PCT= pre-commercial thinning

Table 7. Linear Regression Combinations Conducted for Sensitivity Analysis

Appendix	Prices	Discount rate	Stand Origin	Harvest Age
I.	2005	0.04	Planted	Typical (35)
II.	2005	0.04	Natural	Typical (45)
III	2005	0.04	Planted	Optimal Risk Adjusted SEV
IV.	2005	0.04	Natural	Optimal Risk Adjusted SEV
V.	2005	0.06	Planted	Typical (35)
VI.	2005	0.06	Natural	Typical (45)
VII.	2005	0.06	Planted	Optimal Risk Adjusted SEV
IIX.	2005	0.06	Natural	Optimal Risk Adjusted SEV
IX.	2011	0.04	Planted	Typical (35)
X.	2011	0.04	Natural	Typical (45)
XI.	2011	0.04	Planted	Optimal Risk Adjusted SEV
XII.	2011	0.04	Natural	Optimal Risk Adjusted SEV
XIII.	2011	0.06	Planted	Typical (35)
XIV.	2011	0.06	Natural	Typical (45)
XV.	2011	0.06	Planted	Optimal Risk Adjusted SEV
XVI.	2011	0.06	Natural	Optimal Risk Adjusted SEV

Note: SEV= soil expectation value

RESULTS

Ordinary least squares regressions were run to evaluate combinations of variables and to ascertain the amount that the treatment choice contributed to the SEV and / or Risk Adjusted SEV. The R-squared and other results can be found in Appendix I-XVI. A sensitivity analysis was conducted to determine the effects of changes in discount rates and product pricing on parameter estimates from linear regressions. As expected, risk adjusted SEVs were lower than SEVs. The age that optimal risk adjusted SEVs occurred was earlier than the age of optimal SEVs.

Most trends in parameter estimates were consistent across regression factor combinations from the sensitivity analysis. The rest of the results are only for optimal risk adjusted stands with a 0.06 discount rate and prices from 2011, unless noted otherwise. The 2011 prices were selected because they represent the current market.

The state variables in planted and natural stands resulted in highest optimal risk adjusted SEVs for Kentucky, Arkansas, Virginia, North Carolina, and Texas when compared to the base state, Alabama. Tennessee, South Carolina, and Florida all experienced lower optimal risk adjusted SEVs compared to Alabama. Estimates had larger differences when considering optimal risk adjusted SEVs versus typical risk adjusted SEVs (ages 35 and 45).

Treatment results were conclusive across simulations. Planted stands averaged a loss of -$193 per acre for PCT and increase of $101 per acre for 1st Thin, relative to the control. For natural stands, where only the 1st Thin was evaluated (PCT not typically done on natural stands) the 1st Thin treatment reduced the optimal risk adjusted SEV by an average of -$129 per acre. For planted stands, the estimate for density of the PCT treatments for planted stands produced an estimate (-$0.02 per each additional tree over 400 up to 550 trees) similar to the 1st Thin density treatment estimate (-$0.16 per each additional tree over 400 up to 550 trees). The age of the PCT generated a positive optimal risk adjusted SEV contribution of $9 (per each additional year from 4 up to 8) and the 1st Thin resulted in $0.14 (per each additional year from 12 up to 16). This means, for example, that a change in the harvest age from 4 to 6 years for PCT increased the risk adjusted SEV by $18 per acre, and a change in 1st Thin from 12 to 16 years increased the average by nearly $0.28 per acre. The planted stand treatments exhibited positive estimates for 1st Thin treatments and negative estimates for PCT treatments when compared against the control benchmark. Natural stand estimates demonstrated that 1st Thin treatments were negative in relation to the control benchmark.

Slash pine had a lower risk adjusted SEV compared to loblolly pine when site index, state, physiographic region, and initial density were held constant and the treatment was control. Planted stands averaged a loss of -$131 per acre and natural stands also averaged a loss of -$37 per acre when other variable were kept constant and the treatment was control. Site index was a continuous variable in the regression and assessments can only be taken between the three values. For every 15 ft increase in site index quality, planted stands averaged a gain of $315 per acre in risk adjusted SEV, and natural stands improved $85.50 per acre (15*$21 and 15*$5.70 respectively) under the control treatment. Density at stand origin for planted stands had a loss of $-0.03 (per each additional tree over 500 and up to 1,000 trees) and natural stands lost -$0.23 (per each additional tree over 1000 and up to 2000 trees) under the control treatment. This means that for every increase of 250 trees per acre for planted stands, the risk adjusted SEV, on average, decreased -$7.50 per acre (250*-$0.03) when all other variables were held constant with the control treatment. For natural stands, every increase of 500 trees per acre resulted in a lower risk adjusted SEV of -$115 per acre on average (500*-$0.23) with the control treatment.

Tables 8, 9, 10, and 11 show the resulting parameter estimates from the linear regressions. The sensitivity analysis from the regressions shows that the for each of the 3608 planted and 1476 natural observations, when nothing else is changed, the transition from a 0.06 discount rate to a 0.04 discount rate increases SEVs. The change from 2005 prices to 2011 prices, when all else is kept constant, decreased SEVs greatly. The change in discount rates (from 0.06 to 0.04) provided, on average, an increase to state parameter estimates for planted stands. Natural stands had an increase, on average, to state parameters with discount rate changes of 0.06 to 0.04. Planted stands returned a negative change in parameter estimates when prices were changed from 2005 levels to 2011. The change of prices on natural stands increased state parameter estimates on average. Other variables were more varied in percent of change, but were generally greater when moving from the higher discount rate and lower prices to the lower discount rate and higher prices. These results are similar to those reported by de Steiguer et al. (1987).

Discount rate did alter the estimates of returns by physiographic region enough in planted stands (optimal risk adjusted SEV simulations) that the order of estimates shifted so that regions with lower estimates shifted position and moved in the ranking when compared to the base region East Texas. The order or the estimates compared to the East Texas base, with 0.06 discount rates were Upper Coastal Plain, Lower Coastal Plain, Piedmont, West Gulf Coastal Plain. However, under 0.04 rates, the order changes to the Lower Coastal Plain, Upper Coastal Plain, West Gulf Coastal Plain, and Piedmont. Changes in discount rate had the most effect in altering the parameter estimates.

Table 8. Sensitivity Analysis: Optimal Risk Adjusted SEV (Planted Stands) Effects of Discount Rates and Prices on Parameter Estimates (Planted Stands)

Discount Rate	0.04	0.06	0.04	0.06
Price Year	2005	2005	2011	2011
Mean	1606	646	933	343
Intercept	-3568	-1843	-2202	-1162
Arkansas	143	53	86	31
Florida	-82	-33	-48	-19
Georgia	8	3	5	2
Kentucky	143	53	86	31
Louisiana	-68	-27	-40	-16
Mississippi	-48	-19	-28	-11
North Carolina	90	35	54	21
Oklahoma	-5	-6	-8	-6
South Carolina	-98	-38	-58	-22
Tennessee	-758	-294	-423	-159
Texas	83	34	48	20
Virginia	97	38	58	22
Piedmont	623	229	313	110
West Gulf Coastal Plain	522	225	292	136
Upper Coastal Plain	716	287	379	156
Lower Coastal Plain	643	312	377	195
Slash Pine	-325	-167	-237	-131
Site Index	68	34	42	21
Origin Density	-0.06	-0.07	-0.01	-0.03
PCT	-153	-102	-236	-193
1st Thin	258	200	166	101
Age of PCT	13	9	11	9
Density of PCT	-0.08	-0.10	0.03	0.20
Age of 1st Thin	-0.30	-2.45	3.1	0.14
Density of 1st Thin	-0.50	-0.31	-0.36	-0.16

Note: Units for parameter estimates are $ per acre; PCT= pre-commercial thin

Table 9. Sensitivity Analysis: Optimal Risk Adjusted SEV (Natural Stands) Effects of Discount Rates and Prices on Parameter Estimates (Natural Stands)

Discount Rate	0.04	0.06	0.04	0.06
Price Year	2005	2005	2011	2011
Mean	626	234	482	190
Intercept	140	76	206	83
Arkansas	47	17	25	10
Florida	-31	-11	-16	-7
Georgia	3	1	2	1
Kentucky	47	17	25	10
Louisiana	-26	-9	-13	-6
Mississippi	-18	-6	-9	-4
North Carolina	33	12	17	7
Oklahoma	-15	-4	-7	-3
South Carolina	-36	-13	-19	-8
Tennessee	-259	-97	-144	-62
Texas	34	11	17	7
Virginia	35	12	19	8
Piedmont	-21	-11	-23	-13
West Gulf Coastal Plain	4	8	4	7
Upper Coastal Plain	-8	1	-9	0
Lower Coastal Plain	18	15	19	15
Slash Pine	-178	-76	-84	-37
Site Index	18	8	12	6
Origin Density	-0.57	-.30	-.43	-.23
1st Thin	-344	-161	-313	-129
Age of 1st Thin	9	5	11	5

Note: Units for parameter estimates are $ per acre

Table 10. Sensitivity Analysis: Risk Adjusted SEV (Optimal and Typical) Effects of Discount Rates and Prices on Parameter Estimates of States (Planted Stands)

Discount Rate	0.04	0.06	0.04	0.06	0.06 to 0.04		0.04	0.06
Price Year	2005		2011		2005	2011	2011 to 2005	
Typical (35) Risk Adjusted SEV (Planted)								
Mean	1479	503	830	227	294%	366%	178%	222%
Intercept	-3262	-1515	-2055	-1002	215%	205%	159%	151%
Arkansas	151	69	96	44	219%	218%	157%	157%
Florida	-104	-47	-66	-30	221%	220%	158%	157%
Georgia	9	4	6	3	225%	200%	150%	133%
Kentucky	151	69	96	44	219%	218%	157%	157%
Louisiana	-85	-39	-55	-25	218%	220%	155%	156%
Mississippi	-60	-27	-38	-18	222%	211%	158%	150%
North Carolina	104	47	67	31	221%	216%	155%	152%
Oklahoma	-22	-10	-17	-8	220%	213%	129%	125%
South Carolina	-121	-54	-77	-35	224%	220%	157%	154%
Tennessee	-1205	-526	-768	-338	229%	227%	157%	156%
Texas	97	44	63	29	220%	217%	154%	152%
Virginia	113	51	72	33	222%	218%	157%	155%
Total					222%	217%	154%	150%
Optimal Risk Adjusted SEV (Planted)								
Mean	1606	646	933	343	249%	272%	172%	188%
Intercept	-3568	-1843	-2202	-1162	194%	190%	162%	159%
Arkansas	143	53	86	31	270%	277%	166%	171%
Florida	-82	-33	-48	-19	248%	253%	171%	174%
Georgia	8	3	5	2	267%	250%	160%	150%
Kentucky	143	53	86	31	270%	277%	166%	171%
Louisiana	-68	-27	-40	-16	252%	250%	170%	169%
Mississippi	-48	-19	-28	-11	253%	255%	171%	173%
North Carolina	90	35	54	21	257%	257%	167%	167%
Oklahoma	-5	-6	-8	-6	83%	133%	63%	100%
South Carolina	-98	-38	-58	-22	258%	264%	169%	173%
Tennessee	-758	-294	-423	-159	258%	266%	179%	185%
Texas	83	34	48	20	244%	240%	173%	170%
Virginia	97	38	58	22	255%	264%	167%	173%
Total					243%	249%	160%	165%

Note: Units for parameter estimates are $ per acre; SEV= soil expectation value

Table 11. Sensitivity Analysis: Risk Adjusted SEV (Optimal and Typical) Effects of Discount Rates and Prices on Parameter Estimates of States (Natural Stands)

Discount Rate	0.04	0.06	0.04	0.06	0.06 to 0.04		0.04	0.06
Price Year	2005		2011		2005	2011	2011 to 2005	
Typical (45) Risk Adjusted SEV (Natural)								
Mean	549	158	356	89	347%	400%	154%	178%
Intercept	-70	-94	-65	-92	74%	71%	108%	102%
Arkansas	58	23	38	15	252%	253%	153%	153%
Florida	-41	-16	-27	-10	256%	270%	152%	160%
Georgia	4	1	2	1	400%	200%	200%	100%
Kentucky	58	23	38	15	252%	253%	153%	153%
Louisiana	-34	-13	-22	-9	262%	244%	155%	144%
Mississippi	-24	-9	-16	-6	267%	267%	150%	150%
North Carolina	41	16	27	10	256%	270%	152%	160%
Oklahoma	-18	-7	-13	-5	257%	260%	138%	140%
South Carolina	-47	-18	-31	-12	261%	258%	152%	150%
Tennessee	-465	-171	-304	-113	272%	269%	153%	151%
Texas	41	16	27	11	256%	245%	152%	145%
Virginia	44	17	29	11	259%	264%	152%	155%
Total					271%	255%	155%	147%
Optimal Risk Adjusted SEV (Natural)								
Mean	626	234	482	190	268%	254%	130%	123%
Intercept	140	76	206	83	184%	248%	68%	92%
Arkansas	47	17	25	10	276%	250%	188%	170%
Florida	-31	-11	-16	-7	282%	229%	194%	157%
Georgia	3	1	2	1	300%	200%	150%	100%
Kentucky	47	17	25	10	276%	250%	188%	170%
Louisiana	-26	-9	-13	-6	289%	217%	200%	150%
Mississippi	-18	-6	-9	-4	300%	225%	200%	150%
North Carolina	33	12	17	7	275%	243%	194%	171%
Oklahoma	-15	-4	-7	-3	375%	233%	214%	133%
South Carolina	-36	-13	-19	-8	277%	238%	189%	163%
Tennessee	-259	-97	-144	-62	267%	232%	180%	156%
Texas	34	11	17	7	309%	243%	200%	157%
Virginia	35	12	19	8	292%	238%	184%	150%
Total					293%	233%	190%	152%

Note: Units for parameter estimates are $ per acre; SEV= soil expectation value

Figures 2, 3, 4, and 5 are all representative of data from North Carolina. North Carolina was chosen due to the proximity in relation to the author's location. An individual set of similar stands were selected to show the relationships of the SPB risk on various treatments when other variables are held constant. For this example the following are held constant: state-(NC), physiographic region-(Upper Coastal Plain), site index-(SI85 ft at age 25 years for Figures 2, 3, 4 and SI 100 ft at age 50 for Figure 5), planting density-(1000 TPA for Figures 2, 3, 4, and 2000 TPA for Figure 5), and species-(loblolly pine). These characteristics were chosen to reflect a productive stand. The differences in initial density and site index are reflective of the maximum levels for planted and natural stands.

Figure 2 displays the risk adjusted SEV (optimal rotation age and assumed typical rotation age) for different treatment options for the specific stand selected with a 6% discount rate and 2011 product prices. The 1st Thin treatment had a difference in risk adjusted SEV between the optimal value and the typical harvest age of roughly $80 per acre. The control treatment had a difference in risk adjusted SEV of $119 per acre. The PCT treatment had a reduction in risk adjusted SEV of just over $130 per acre. On average, stands that were managed according to assumed typical regime ages led to risk adjusted SEVs $100-$200 lower than the optimal for each specific treatment that was conducted. These results were common across all simulations. An example of these results can be seen in Figure 2.

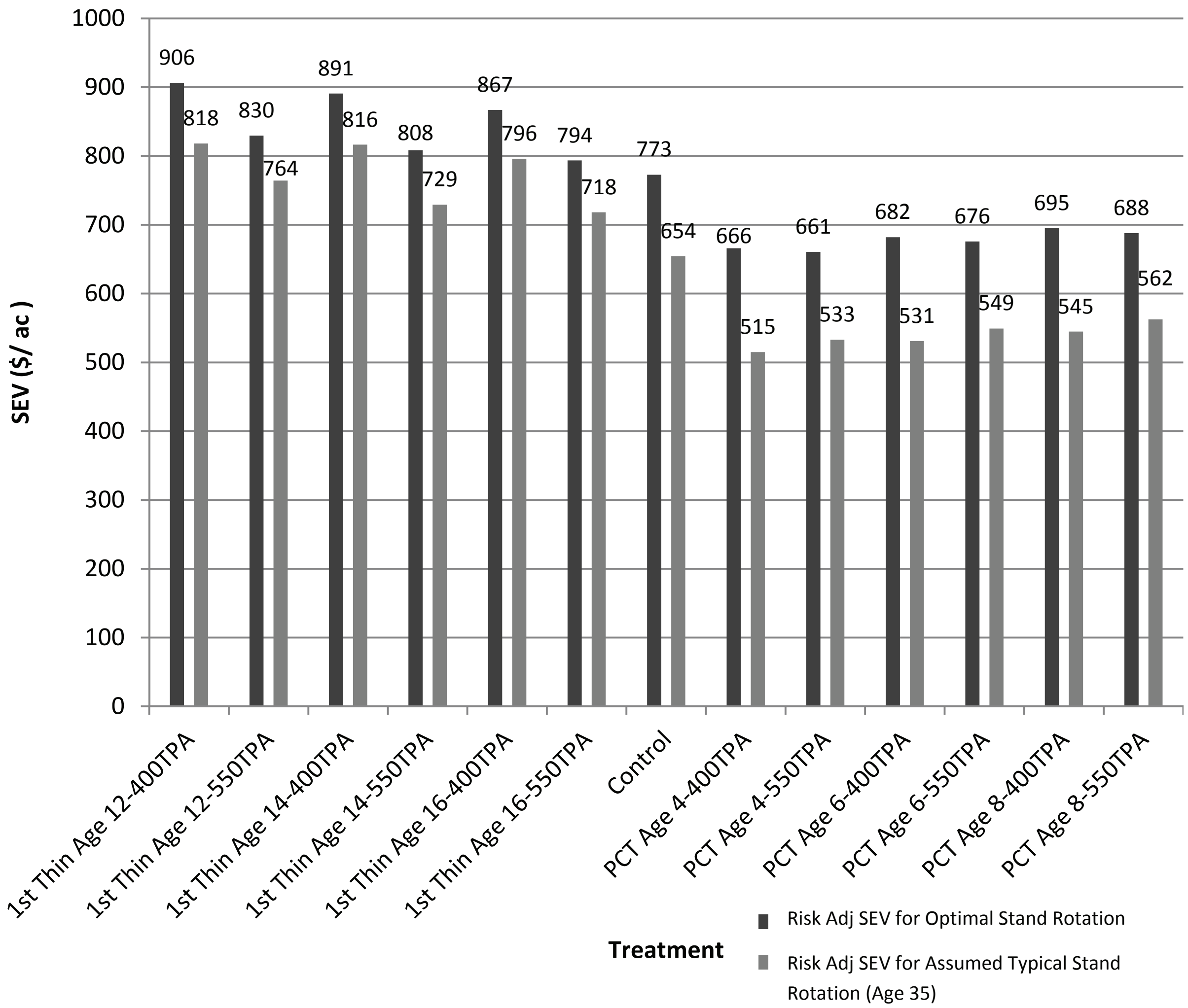

Figure 2. Optimal and Typical (Age 35) Risk Adjusted SEV of Treatments for Planted Stands in NC, Upper Coastal Plain, SI 85, Loblolly pine, Planting Density 1000 TPA, 6% Discount Rate and 2011 Product Prices

Figure 3 demonstrates the planted stand relationships between treatment and risk adjusted SEV when product pricing is from 2011 and the discount rate is 6%. The trend of higher estimates from the 1st Thin and lower estimates from the PCT compared to the control (benchmark) treatment are apparent. The highest risk adjusted SEV is the 1st Thin Age 12-400 TPA treatment at $906. The control treatment returned a risk adjusted SEV of $773. The lowest treatment risk adjusted SEV was PCT Age 4-550 TPA at $661. The age of 1st Thin treatments produced lower risk adjusted SEVs with increased age by about -$18. This is not consistent with the results of the linear regressions (-$0.14 per additional year added from the regression estimate). However, the t- Value for the age of 1st thin variable was not significant with a probability of 0.85 reflecting the erratic and perhaps non-normal distribution of the simulations.

The changes in density for the 1st Thin treatments decreased the risk adjusted SEV as density increased by roughly -$75 on average, and is also in support of the linear regression (-$0.16 per additional tree per acre from the regression). The PCT treatment age results were similar. They supported the linear regression estimates by increasing risk adjusted SEV with age of treatment by about $14 ($9 from regression estimate). The density of the PCT treatment was not in support of the average estimates produced by the linear regression with increased density lowering the risk adjusted SEV by roughly -$6 ($0.02 per additional tree per acre from the regression). However, the probability for this variable was again found insignificant in the linear regression (0.19). These findings were consistent with the results of the linear regression (1st Thin treatment $101 and PCT -$193 compared to the intercept from the regression parameter estimates) and are common in the simulations that were run.

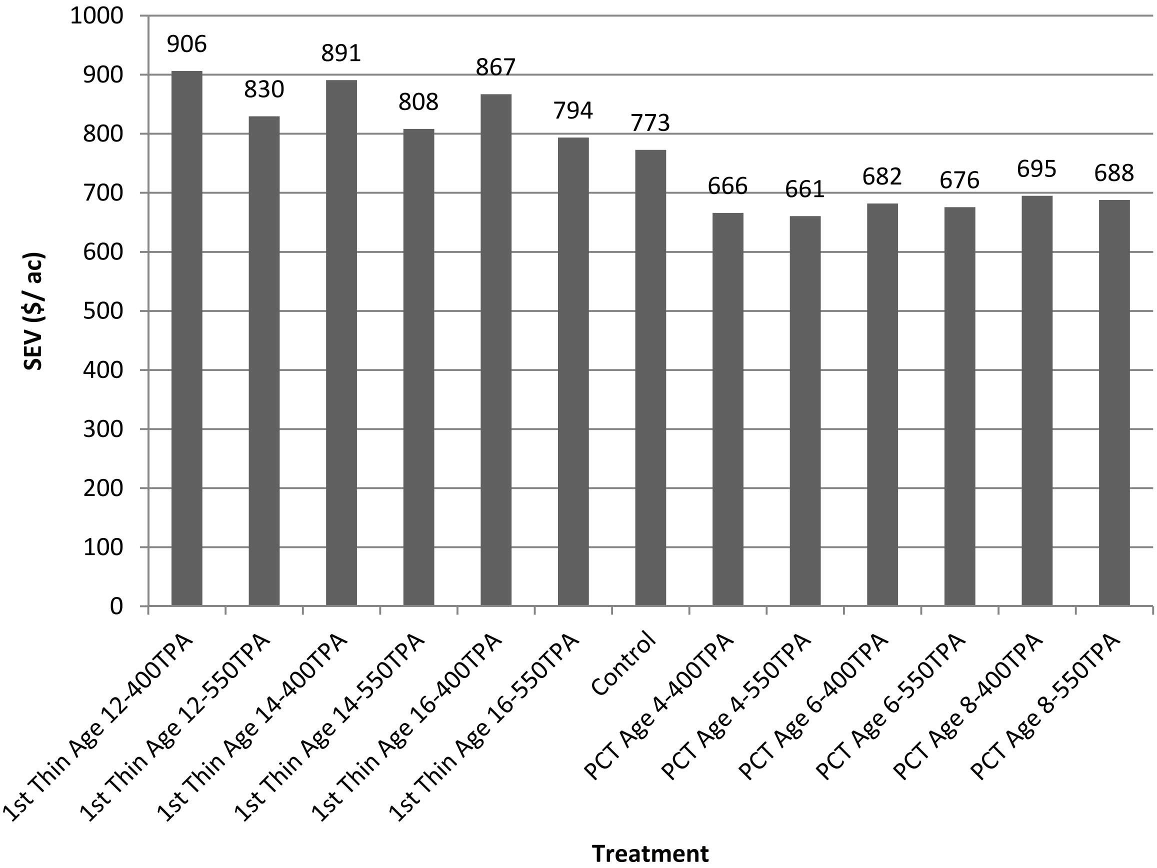

Figure 3. Optimal Risk Adjusted SEV of Treatments for Planted Stands with 0.06 Discount Rate and 2011 Prices for NC, Upper Coastal Plain, SI 85, Loblolly pine, Planting Density 1000 TPA

Overall risk adjusted SEVs are higher and the differences greater between treatments for 2005 prices when the product prices are altered from 2011 using as 6% discount rate (as seen when comparing Fig. 4 and Fig 3.). 1st Thin Age 12 to 400 TPA had the highest risk adjusted SEV treatment at $1,444. The control treatment had a risk adjusted SEV of $1,320. The lowest risk adjusted SEV was the PCT Age 4-550 TPA treatment at $1,256.

The age of the 1st Thin treatment variable, averaged a decline in risk adjusted SEV with an increase in age by about -$22 (regression estimate of -$2.45 per additional year). The density of the 1st Thin treatment averaged a decrease in risk adjusted SEV with an increase in density by about -$80 (regression estimate of -$0.31 per additional tree per acre). The age of the PCT treatment averaged an increase in risk adjusted SEVs of $14 (regression estimate of $9 per additional year). The density of the PCT treatment averaged a decrease in risk adjusted SEV of -$24 (regression estimate of -$0.10).

This stand agreed with the results from the regression. The 1st Thinning treatment results (regression estimate $200) were higher than the control treatment and the PCT treatment had the lowest risk adjusted SEVs (regression estimate -$102). The risk adjusted SEVs and the differences between the variables are both greater than those compared to the results from Figure 3 with different product pricing.

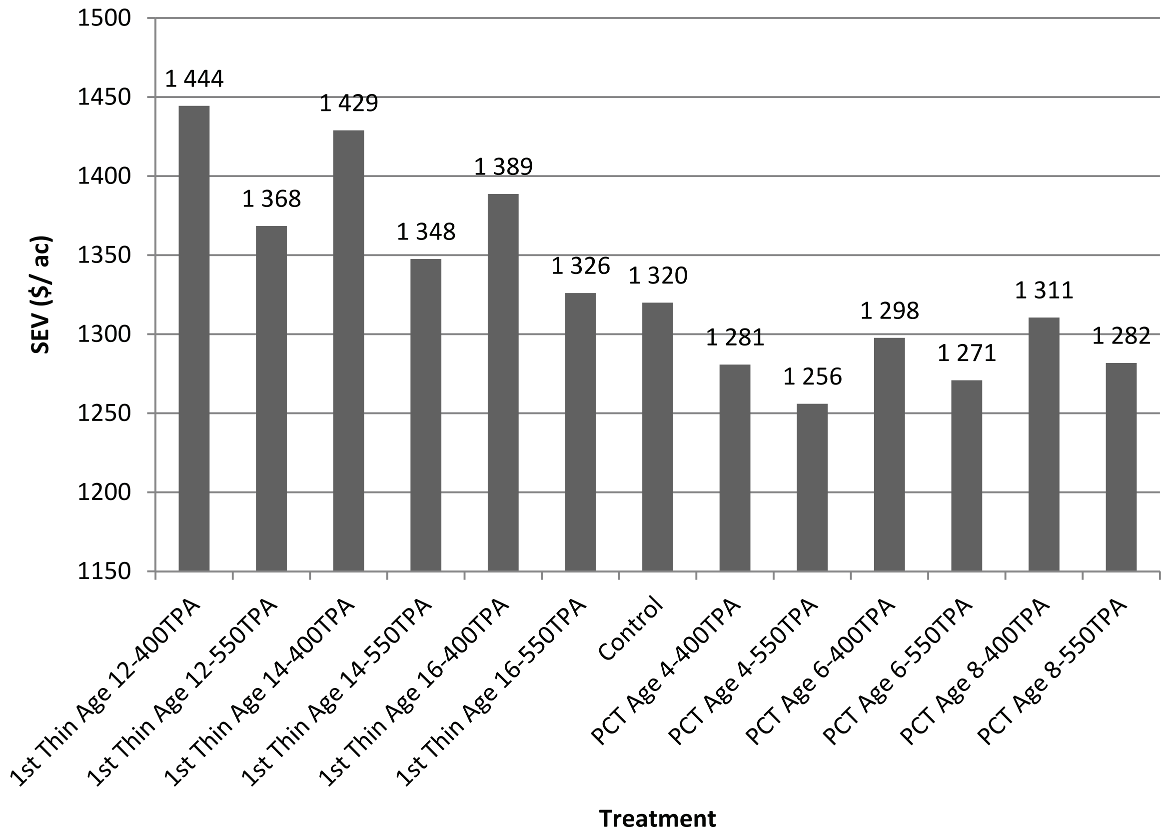

Figure 4. Optimal Risk Adjusted SEV of Treatments for Planted Stands with 0.06 Discount Rate and 2005 Prices for NC, Upper Coastal Plain, SI 85, Loblolly pine, Planting Density 1000 TPA

Figure 5 examines treatments and risk adjusted SEVs for natural stands with 2011 product pricing. The control treatment had the highest risk adjusted SEV at $200 followed consecutively by the 1st Thin treatments in order of treatment age: 1st Thin Age 25- 550 TPA ($182), 1st Thin Age 20-550 TPA ($148), and 1st Thin Age 15-550 TPA ($101) (regression estimate of -$129 for conducting 1st Thin treatment). The 1st Thin treatment averaged an increase in risk adjusted SEV of about $41 with an increase in treatment age (regression estimate was $4.74 per additional year). Natural stand risk adjusted SEVs were substantially lower than the planted stands. The control treatment in natural stands seemed on average to produce higher risk adjusted SEVs compared to the alternative thinning option. However, natural stands did still produce positive SEVs.

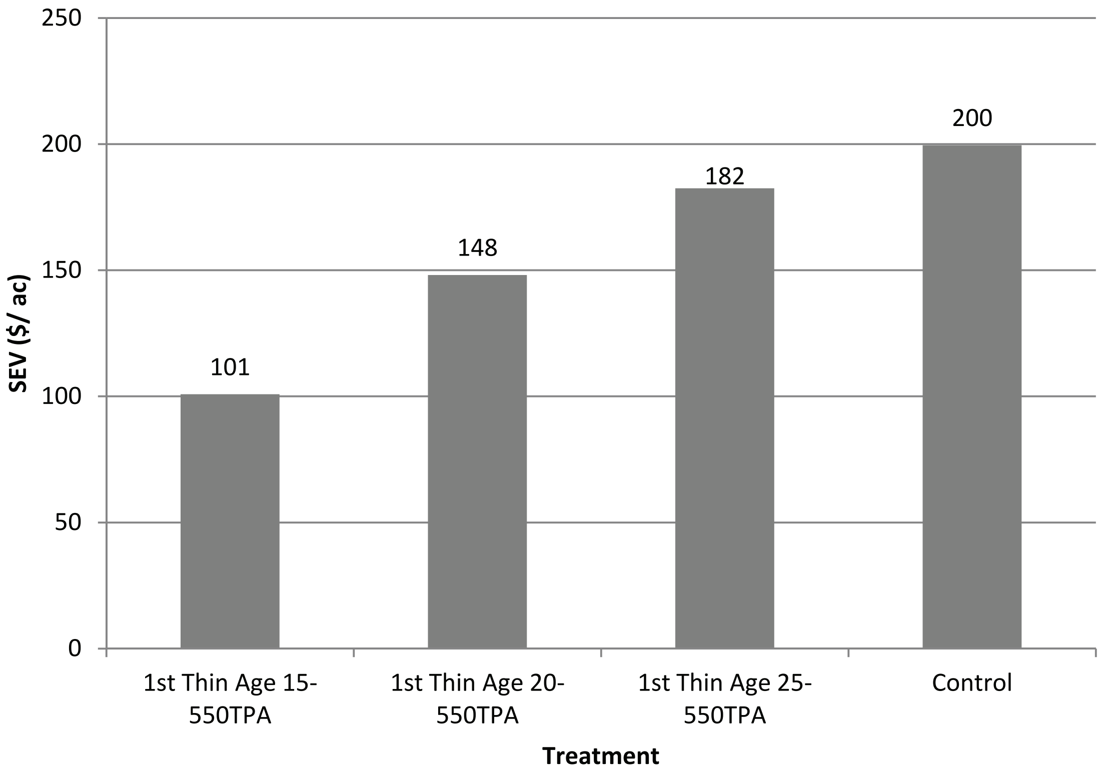

Figure 5. Optimal Risk Adjusted SEV of Treatments for Natural Stands with 0.06 Discount Rate and 2011 Prices for NC, Upper Coastal Plain, SI 100, Loblolly Pine, Initial Density of 2000 TPA

The following summary of results refers to stands with 0.06 discount rates and 2005 product pricing. Optimal values were higher than typical risk adjusted SEVs. Still, it is important to examine both optimal and typical rotation lengths, because landowners can understand that under set conditions higher risk adjusted SEVs can be obtained with different rotation lengths than are currently practiced. Arkansas, Kentucky, Virginia, and Texas consistently had higher risk adjusted SEVs compared to Alabama the benchmark when all other factors were held constant. Tennessee, Florida, and South Carolina consistently had lower risk adjusted SEVs compared to Alabama. Initial density also had risk adjusted SEVs that declined with increased trees per acre. This finding is supported by Amateis and Burkhart (2012), Anton-Fernandez et al. (2011), and Huang et al. (2005). The site index variable had a positive influence on the stand risk adjusted SEV.

With an increase in age of PCT treatment, the risk adjusted SEVs averaged an increase in risk adjusted SEV in planted stands. For 1st Thin treatments in planted stands, the risk adjusted SEVs declined with an increase in age. The opposite was true for 1st Thin treatments in natural stands. These treatments increased in risk adjusted SEV with increases in age of the 1st Thin treatment. With increased treatment thinning densities for planted stands, the risk adjusted SEVs averaged a decrease. Most importantly, the planted stand PCTs exhibited lower estimates than the control, which supports the hypothesis of this research. The 1st Thin treatments produced higher estimates than the control for planted stands. This fails to support the hypothesis. Confirming the hypothesis, natural stands generated higher estimates in the control treatments compared to the alternative 1st Thin option. Thus, mixed results were found for the hypothesis that sponsored treatments will not result in higher risk adjusted SEVs.

DISCUSSION

To assess the economic impact of SPB on typical stands of the Southeast, growth and yield simulations were run and economic analyses were incorporated into the product reports. The results give some insight on the costs and benefits of treatments representative of those sponsored by the SPB Prevention Program. The sensitivity analysis found that results for states, species, planting density, site index, and treatment were conclusive regardless of the discount rate or product pricing applied.

However, fixed assumptions that could affect the outcomes of the sensitivity analysis include: the assumed 80% pine stocking level for each forest stand, the assumption of a 10% return in revenue from salvage situations, and the time period for the state level calculations for risk of SPB caused tree mortality. Different stands will have different pine stocking levels and those effects may differ. Salvage situations may not necessarily produce revenues of 10%. This rate could vary significantly. The time period was selected based off of availability of data. However, different time periods may have different risk ratings for SPB based off of the ever changing dynamics of all of the inputs influencing SPB ecology (Reed et al., 1982; and Gan, 2004). There may be inaccuracies in the data provided by the states to the USFS as well. Another assumption was made regarding the SPB risk rating for each state. The rating is an estimate for the entire state, but the scale of this study is on a 1 acre stand basis. Individual stand risk rates for SPB caused mortality may differ widely between different stands within each state.

Adjusted SEVs for SPB risk were lower than SEVs without SPB risk. This is to be expected when an investment risk is incorporated into an economic analysis. Optimal risk adjusted SEVs occurred slightly earlier in the rotation compared to SEVs without risk. Again, this is to be expected because the penalty from the SPB risk prohibits the stand from reaching its potential at a later age and higher SEVs. Planted stands had higher optimal risk adjusted SEVs compared to natural stands. The optimal risk adjusted SEVs occurred before the assumed typical harvest age for planted and natural stands.

Planted treatment estimates found that 1^{st} Thin options had on average higher risk adjusted SEVs than control treatments. PCT treatments were found to consistently have lower risk adjusted SEVs than the control treatments. The results may have been due to the time value of the cost for the PCT; the earlier the PCT occurred the lower the estimates. It suggests that the early PCTs are most disadvantageous because they have to hold the costs for a longer time span which counts poorly in relation to the SEV. The 1^{st} Thin treatments generated revenue not costs and so 1^{st} Thins that occurred earlier in the stand had a more positive impact on SEVs than later treatments. The earlier treatments provided revenue earlier in the life of the stand that helped the profitability of these treatments by injecting benefits earlier in the life of the stand. In both treatment options higher thinning densities resulted in a decline in risk adjusted SEVs, suggesting that the less thinning options, on average, were the best choice.

In natural stands, the control treatment had the highest risk adjusted SEVs. The reason for this is likely twofold. First, the product class available at thinning ages would tend to be predominantly pulpwood because of the higher density from the beginning of the stand. The high density creates competition for resources among the young trees and slows growth. Since the trees end up growing slowly in the early life of the stand, a thinning generates little revenue because most stems are still in the lowest product class. Second, once the thinning treatments occur the trees attempt to utilize the additional resources available, however, there is a limit to how much value they can add until final harvest. Future revenues take so long to accumulate that they cannot compete economically compared to planted stands or a natural stand that is not thinned (control treatment) given the assumptions provided. Natural stands did not have a PCT treatment or multiple density components in the thinning treatment. NIPF owners who prefer to manage their stands with natural regeneration should not participate in any thinning treatment.

Compared to Alabama, the results indicate that for both planted and natural stands Arkansas, Kentucky, Virginia, Texas, and North Carolina had the highest SEVs. Tennessee, South Carolina, and Florida had lower estimated results. Loblolly pine returns seemed better than slash pine, all else held constant (physiographic region, state, site index, initial density, and treatment). As expected higher site indices had higher returns than lower site indices. Since the SEV proportions in general were consistent across treatments, it can be said that the treatment was not the driver for the performance of regions, species, and state. The main drivers affecting those results were attributed to the SiMS growth and yield models for physiographic region and species, as well as the different SPB risks associated with each state. Individually these two variables do not describe the results, but when considered together they could be useful for predicting outcomes of potential risk adjusted SEVs from a variety of treatments.

When looking at the state results, the states with the highest SPB risks had low SEVs, whereas the states with low SPB risks had higher relative SEVs. However, states with the highest SPB risks may have higher site indices and prices. Tennessee, Florida and South Carolina were affected particularly severely over the time period covered in the USFS SPB data. They each had the three highest risk probabilities. Pye et al. (2011), Hain et al. (2011), and Birt (2011) give evidence to support the results for the Tennessee and South Carolina parameter estimates. Since the SPB risk rating acts as a penalty on SEVs, the outcome is as would be expected. The opposite is true for Arkansas, Kentucky, Virginia, Texas, and North Carolina. They each had lower risks compared to some of the states with lower SEVs. Because of this, these states consistently had the highest risk adjusted SEVs.

The physiographic region parameter estimate order rankings were inconsistent in the sensitivity analysis. The Lower Coastal Plain and Upper Coastal Plain were the only two regions with the highest parameter estimates suggesting they are generally the most profitable compared to East Texas, the intercept. Alternatively, the Piedmont and West Gulf Coastal

Plain were the only regions with the lowest parameter estimates suggesting they are generally the least profitable in relation to the intercept. These results are likely due to the product outputs from the SiMS growth and yield model, and the pricing for each product. Stands that are growing in a predominantly lower product class have lower value and will be less profitable. Regions where growth is considered better will have more products in higher classes and in effect generate higher revenues. Generally, the Lower Coastal Plain and Upper Coastal Plain are considered to be more productive than the Piedmont and West Gulf Coastal Plain.

NIPF owners should actively manage their stand to get a better SEV from their land. Of course, many other factors affect the management decisions of NIPF owners. The planted stands had higher SEV estimates, but natural stands were still capable of providing positive SEVs. Given the set of assumptions for each stand, NIPF owners could be missing out on additional financial value by prolonging the rotation age of their forest stand. NIPF owners should consider performing 1st Thins on planted stands and following the control treatment for natural stands that meet similar characteristics to those modeled in this study. By doing so, they may be able to increase the value of their stand when including the risk of SPB.

Economically, it doesn't make sense to support the treatment that performs the worst. However, it could be said that the cost share program could make the PCT treatment more competitive in respect to the other options. This would only be justified if it could be proven that a PCT treatment provides better ecological benefits per cost-share dollar when compared to the other options. An ecological benefits analysis is beyond the scope of this research. The inclusion of risk in decision making is a judgment that must be made by each individual NIPF owner. This model provides a tool in shaping management decisions based off similar inputs.

FUTURE RESEARCH

Future work can build on this research by performing an ecological analysis in conjunction with economics to determine the best treatment method(s). Specific cost share contributions should be incorporated to truly assess how the SPBPRP cost shares affect the SEV of NIPF owners. The ecology of the SPB is that it has different risk probabilities based off of many factors. The effects of a low population compared to a high population can be very different. It would be important to include catastrophic beetle risks in a future analysis. Mass salvage harvest from the SPB can have extensive repercussions on local and regional wood markets. Incorporating the economic effects would make this analysis more meaningful. Economic analysis regarding the difference between SPB risk of natural and planted stands on the effect of SEV could be performed. Assuming there is a different risk between planted and natural stands, research could determine if there were certain thresholds that, if reached, would make natural stands more preferred than planted stands.

Climate change is dynamic and has significant effects on the SPB and its hosts. Beetle populations and host location projections should continue to be refined and updated. With accurate, up to date host and beetle information, this tool could be much more specific and useful at pinpointing problem areas to concentrate prevention funding.

Another avenue for research would be to add weights to each stand simulation based off of state and physiographic region data provided by the USFS Forest Inventory and Analysis Program. If successful, tests for significance and other pertinent statistical procedures could be conducted on the research to determine the fit level. With accurate data and an improved model, a product could be developed for NIPF owners to use as a management guideline. Forest owners could then reference the tool and manage their forests based off of specific recommendation that suits their management/ risk profile. Finally, the perspective of this analysis was conducted for NIPF owners. A separate, yet similar analysis should be conducted for the government with new costs and benefits to justify the funds being distributed for SPB prevention treatments.

CONCLUSION

The Southern Pine Beetle is a native pest that has and will continue to cause significant mortality to trees located in forests throughout the Southeast U.S. This project created an assessment tool applicable to the time period from the late 1970s to early 2000s. The results are representative of site conditions during this time period in the SE US region. The scale of their application is only to the physiographic regions within each state. The results support the assessment that commercial thinnings offer the best economic option for active (plantation management) NIPF owners to generate higher SEVs when considering the treatment options associated with the SPB Prevention and Restoration Program. NIPF owners who would prefer to manage their forests naturally (passive management), may best be able to generate higher SEVs by not participating in some of the treatments promoted by the SPB PRP.

The cost share program created by the SPB PRP will yield positive returns for NIPF owners, but certain aspects may not be the best economic value for both the government and NIPF owners. Since PCT treatments for planted stands and 1st Thin treatments for natural stands performed worse than other options for planted and natural stands respectively, the cost share program may be promoting treatments that are less economically beneficial. A typical NIPF landowner can achieve almost as good or better of a return simply by not participating in the program, not conducting treatments, and following the methods suggested in the control. In the absence of the incentives provided by the SPB Prevention Program, NIPF owners would likely refrain from conducting PCT (planted) and commercial thinning (natural) treatments that resulted in lower risk adjusted SEVs than the control. This study should only be applied to future years, with caution, if updated SPB risk data is obtained. Future research is necessary in determining the ecological benefit of the program to forests in the Southeast.

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APPENDICES

APPENDIX I. Linear Regression: Risk Adjusted SEV at Typical (Age 35) Planted Stands, 0.04 Discount Rate, 2005 Prices

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	25	2410486352	96419454	3800.09	<.0001
Error	3582	90885836	25373		
Corrected Total	3607	2501372188			
Root MSE		159.28883	R-Square	0.9637	

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	-3262.33325	34.13151	-95.58	<.0001
Arkansas	1	151.11489	14.94498	10.11	<.0001
Florida	1	-103.63263	13.15938	-7.88	<.0001
Georgia	1	9.46059	12.02394	0.79	0.4314
Kentucky	1	151.11489	14.94498	10.11	<.0001
Louisiana	1	-85.45573	13.15938	-6.49	<.0001
Mississippi	1	-59.87642	13.15938	-4.55	<.0001
North Carolina	1	103.89002	12.02394	8.64	<.0001
Oklahoma	1	-21.54294	32.27296	-0.67	0.5045
South Carolina	1	-120.57422	12.02394	-10.03	<.0001
Tennessee	1	-1205.47638	14.94498	-80.66	<.0001
Texas	1	97.36474	21.40697	4.55	<.0001
Virginia	1	112.50698	12.02394	9.36	<.0001
Piedmont	1	791.20219	27.01482	29.29	<.0001
West Gulf Coastal Plain	1	659.57137	21.17609	31.15	<.0001
Upper Coastal Plain	1	874.96378	26.36754	33.18	<.0001
Lower Coastal Plain	1	708.63366	26.32742	26.92	<.0001
Slash Pine	1	-379.19962	7.69642	-49.27	<.0001
Site Index	1	60.30704	0.21757	277.18	<.0001
Origin Density	1	-0.00648	0.01576	-0.41	0.6809
PCT	1	-204.50959	28.89009	-7.08	<.0001
1st Thin	1	275.46162	47.3651	5.82	<.0001
Age of PCT	1	16.02747	2.27092	7.06	<.0001
Density of PCT	1	-0.00844	0.05215	-0.16	0.8715
Age of 1st Thin	1	1.29818	2.65098	0.49	0.6244
Density of 1st Thin	1	-0.51783	0.0586	-8.84	<.0001

Note: PCT= pre-commercial thin

APPENDIX II. Linear Regression: Risk Adjusted SEV at Typical (Age 45) Natural Stands, 0.04 Discount Rate, 2005 Prices

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	21	119085135	5670721	1018.33	<.0001
Error	1454	8096808	5568.64392		
Corrected Total	1475	127181943			
Root MSE		74.62335	R-Square	0.9363	

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	-70.32018	26.00797	-2.7	0.0069
Arkansas	1	58.1502	11.03263	5.27	<.0001
Florida	1	-41.14919	9.59867	-4.29	<.0001
Georgia	1	3.72471	8.79445	0.42	0.672
Kentucky	1	58.1502	11.03263	5.27	<.0001
Louisiana	1	-33.97729	9.59867	-3.54	0.0004
Mississippi	1	-23.88375	9.59867	-2.49	0.0129
North Carolina	1	40.9057	8.79445	4.65	<.0001
Oklahoma	1	-18.42391	23.58364	-0.78	0.4348
South Carolina	1	-47.46551	8.79445	-5.4	<.0001
Tennessee	1	-465.44444	11.03263	-42.19	<.0001
Texas	1	41.44013	15.71048	2.64	0.0084
Virginia	1	44.29887	8.79445	5.04	<.0001
Piedmont	1	-14.05368	20.54987	-0.68	0.4942
West Gulf Coastal Plain	1	7.76707	15.48422	0.5	0.616
Upper Coastal Plain	1	-2.14021	20.09232	-0.11	0.9152
Lower Coastal Plain	1	17.62711	19.27753	0.91	0.3607
Slash Pine	1	-127.5755	5.5621	-22.94	<.0001
Site Index	1	15.91631	0.15859	100.36	<.0001
Origin Density	1	-0.39815	0.00476	-83.68	<.0001
1st Thin	1	-234.2671	11.86807	-19.74	<.0001
Age of 1st Thin	1	6.14106	0.54938	11.18	<.0001

APPENDIX III. Linear Regression: Risk Adjusted SEV at Optimal Planted Stands, 0.04 Discount Rate, 2005 Prices

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	25	2764962851	110598514	5067.26	<.0001
Error	3582	78181129	21826		
Corrected Total	3607	2843143980			
Root MSE		147.73663	R-Square	0.9725	

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	-3567.76186	31.65617	-112.7	<.0001
Arkansas	1	142.78076	13.86112	10.3	<.0001
Florida	1	-81.90779	12.20502	-6.71	<.0001
Georgia	1	7.99138	11.15192	0.72	0.4737
Kentucky	1	142.78076	13.86112	10.3	<.0001
Louisiana	1	-67.85345	12.20502	-5.56	<.0001
Mississippi	1	-47.85398	12.20502	-3.92	<.0001
North Carolina	1	89.65869	11.15192	8.04	<.0001
Oklahoma	1	-5.25377	29.93241	-0.18	0.8607
South Carolina	1	-98.3217	11.15192	-8.82	<.0001
Tennessee	1	-757.66475	13.86112	-54.66	<.0001
Texas	1	82.50212	19.85446	4.16	<.0001
Virginia	1	97.27787	11.15192	8.72	<.0001
Piedmont	1	623.1069	25.05561	24.87	<.0001
West Gulf Coastal Plain	1	522.41762	19.64032	26.6	<.0001
Upper Coastal Plain	1	715.58875	24.45527	29.26	<.0001
Lower Coastal Plain	1	643.34845	24.41806	26.35	<.0001
Slash Pine	1	-325.47619	7.13825	-45.6	<.0001
Site Index	1	68.47378	0.20179	339.33	<.0001
Origin Density	1	-0.0585	0.01461	-4	<.0001
PCT	1	-152.96608	26.79487	-5.71	<.0001
1st Thin	1	257.98746	43.93001	5.87	<.0001
Age of PCT	1	12.66767	2.10623	6.01	<.0001
Density of PCT	1	-0.08239	0.04836	-1.7	0.0886
Age of 1st Thin	1	-0.29736	2.45873	-0.12	0.9037
Density of 1st Thin	1	-0.49641	0.05435	-9.13	<.0001

Note: PCT= pre-commercial thin

APPENDIX IV. Linear Regression: Risk Adjusted SEV at Optimal Natural Stands, 0.04 Discount Rate, 2005 Prices

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	21	172875315	8232158	776.07	<.0001
Error	1454	15423284	10607		
Corrected Total	1475	188298599			
Root MSE		102.99265	R-Square	0.9181	

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	139.60034	35.89533	3.89	0.0001
Arkansas	1	46.8904	15.22687	3.08	0.0021
Florida	1	-30.96135	13.24777	-2.34	0.0196
Georgia	1	2.89326	12.1378	0.24	0.8116
Kentucky	1	46.8904	15.22687	3.08	0.0021
Louisiana	1	-25.7245	13.24777	-1.94	0.0524
Mississippi	1	-18.25898	13.24777	-1.38	0.1683
North Carolina	1	32.68644	12.1378	2.69	0.0072
Oklahoma	1	-15.22215	32.54935	-0.47	0.6401
South Carolina	1	-35.65582	12.1378	-2.94	0.0034
Tennessee	1	-259.20016	15.22687	-17.02	<.0001
Texas	1	33.61313	21.68307	1.55	0.1213
Virginia	1	35.49958	12.1378	2.92	0.0035
Piedmont	1	-21.35674	28.36225	-0.75	0.4516
West Gulf Coastal Plain	1	4.04041	21.3708	0.19	0.8501
Upper Coastal Plain	1	-8.33224	27.73075	-0.3	0.7639
Lower Coastal Plain	1	17.7814	26.60621	0.67	0.504
Slash Pine	1	-177.92632	7.67662	-23.18	<.0001
Site Index	1	17.90235	0.21889	81.79	<.0001
Origin Density	1	-0.57122	0.00657	-86.99	<.0001
1st Thin	1	-343.60219	16.37991	-20.98	<.0001
Age of 1st Thin	1	9.28876	0.75824	12.25	<.0001

APPENDIX V. Linear Regression: Risk Adjusted SEV at Typical (Age 35) Planted Stands, 0.06 Discount Rate, 2005 Prices

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	25	457231193	18289248	3685.57	<.0001
Error	3582	17775288	4962.39183		
Corrected Total	3607	475006480			
Root MSE		70.44425	R-Square	0.9626	

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	-1514.9703	15.0944	-100.37	<.0001
Arkansas	1	68.74	6.6093	10.4	<.0001
Florida	1	-46.83326	5.81964	-8.05	<.0001
Georgia	1	4.28965	5.31749	0.81	0.4199
Kentucky	1	68.74	6.6093	10.4	<.0001
Louisiana	1	-38.6484	5.81964	-6.64	<.0001
Mississippi	1	-27.11293	5.81964	-4.66	<.0001
North Carolina	1	47.25622	5.31749	8.89	<.0001
Oklahoma	1	-10.12868	14.27247	-0.71	0.478
South Carolina	1	-54.43308	5.31749	-10.24	<.0001
Tennessee	1	-526.23449	6.6093	-79.62	<.0001
Texas	1	44.44245	9.46707	4.69	<.0001
Virginia	1	51.19068	5.31749	9.63	<.0001
Piedmont	1	337.02647	11.9471	28.21	<.0001
West Gulf Coastal Plain	1	290.70253	9.36496	31.04	<.0001
Upper Coastal Plain	1	382.05478	11.66084	32.76	<.0001
Lower Coastal Plain	1	311.29468	11.6431	26.74	<.0001
Slash Pine	1	-165.5292	3.40368	-48.63	<.0001
Site Index	1	25.90946	0.09622	269.28	<.0001
Origin Density	1	-0.016	0.00697	-2.3	0.0217
PCT	1	-143.12144	12.77642	-11.2	<.0001
1st Thin	1	216.94343	20.94685	10.36	<.0001
Age of PCT	1	10.72065	1.0043	10.67	<.0001
Density of PCT	1	-0.02797	0.02306	-1.21	0.2253
Age of 1st Thin	1	-0.11163	1.17238	-0.1	0.9242
Density of 1st Thin	1	-0.36093	0.02592	-13.93	<.0001

Note: PCT= pre-commercial thin

APPENDIX VI. Linear Regression: Risk Adjusted SEV at Typical (Age 45) Natural Stands, 0.06 Discount Rate, 2005 Prices

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	21	16773650	798745	999.91	<.0001
Error	1454	1161478	798.8158		
Corrected Total	1475	17935128			
Root MSE		28.26333	R-Square	0.9352	

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	-93.74332	9.85043	-9.52	<.0001
Arkansas	1	22.59648	4.17857	5.41	<.0001
Florida	1	-15.81396	3.63546	-4.35	<.0001
Georgia	1	1.43907	3.33087	0.43	0.6658
Kentucky	1	22.59648	4.17857	5.41	<.0001
Louisiana	1	-13.06936	3.63546	-3.59	0.0003
Mississippi	1	-9.19909	3.63546	-2.53	0.0115
North Carolina	1	15.8704	3.33087	4.76	<.0001
Oklahoma	1	-7.2307	8.93222	-0.81	0.4184
South Carolina	1	-18.23383	3.33087	-5.47	<.0001
Tennessee	1	-171.22985	4.17857	-40.98	<.0001
Texas	1	16.11131	5.95029	2.71	0.0069
Virginia	1	17.19344	3.33087	5.16	<.0001
Piedmont	1	-5.91638	7.78319	-0.76	0.4473
West Gulf Coastal Plain	1	8.88497	5.86459	1.52	0.13
Upper Coastal Plain	1	4.89262	7.6099	0.64	0.5204
Lower Coastal Plain	1	12.93815	7.3013	1.77	0.0766
Slash Pine	1	-43.93767	2.10662	-20.86	<.0001
Site Index	1	6.01289	0.06007	100.1	<.0001
Origin Density	1	-0.15376	0.0018	-85.33	<.0001
1st Thin	1	-77.15696	4.49499	-17.17	<.0001
Age of 1st Thin	1	2.89192	0.20808	13.9	<.0001

APPENDIX VII. Linear Regression: Risk Adjusted SEV at Optimal Planted Stands, 0.06 Discount Rate, 2005 Prices

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	25	672391106	26895644	4572.31	<.0001
Error	3582	21070333	5882.28159		
Corrected Total	3607	693461439			
Root MSE		76.69603	R-Square	0.9696	

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	-1843.35004	16.43399	-112.17	<.0001
Arkansas	1	53.16792	7.19586	7.39	<.0001
Florida	1	-32.79825	6.33612	-5.18	<.0001
Georgia	1	3.12589	5.78941	0.54	0.5893
Kentucky	1	53.16792	7.19586	7.39	<.0001
Louisiana	1	-27.17209	6.33612	-4.29	<.0001
Mississippi	1	-19.17173	6.33612	-3.03	0.0025
North Carolina	1	35.11032	5.78941	6.06	<.0001
Oklahoma	1	-5.65286	15.53912	-0.36	0.716
South Carolina	1	-38.49867	5.78941	-6.65	<.0001
Tennessee	1	-293.72683	7.19586	-40.82	<.0001
Texas	1	34.349	10.30725	3.33	0.0009
Virginia	1	38.09717	5.78941	6.58	<.0001
Piedmont	1	229.37369	13.00738	17.63	<.0001
West Gulf Coastal Plain	1	225.46161	10.19608	22.11	<.0001
Upper Coastal Plain	1	286.87275	12.69572	22.6	<.0001
Lower Coastal Plain	1	311.52771	12.6764	24.58	<.0001
Slash Pine	1	-167.18957	3.70575	-45.12	<.0001
Site Index	1	34.10585	0.10476	325.57	<.0001
Origin Density	1	-0.06988	0.00759	-9.21	<.0001
PCT	1	-101.94441	13.9103	-7.33	<.0001
1st Thin	1	199.54388	22.80584	8.75	<.0001
Age of PCT	1	9.33643	1.09343	8.54	<.0001
Density of PCT	1	-0.09708	0.02511	-3.87	0.0001
Age of 1st Thin	1	-2.44993	1.27642	-1.92	0.055
Density of 1st Thin	1	-0.31384	0.02822	-11.12	<.0001

Note: PCT= pre-commercial thin

APPENDIX VIII. Linear Regression: Risk Adjusted SEV at Optimal Natural Stands, 0.06 Discount Rate, 2005 Prices

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	21	40094463	1909260	653.51	<.0001
Error	1454	4247937	2921.55236		
Corrected Total	1475	44342400			
Root MSE		54.05139	R-Square	0.9042	

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	74.59876	18.83816	3.96	<.0001
Arkansas	1	16.96816	7.99119	2.12	0.0339
Florida	1	-10.81324	6.95254	-1.56	0.1201
Georgia	1	1.02209	6.37002	0.16	0.8725
Kentucky	1	16.96816	7.99119	2.12	0.0339
Louisiana	1	-8.97368	6.95254	-1.29	0.197
Mississippi	1	-6.35933	6.95254	-0.91	0.3605
North Carolina	1	11.50665	6.37002	1.81	0.0711
Oklahoma	1	-4.21921	17.08217	-0.25	0.8049
South Carolina	1	-12.5676	6.37002	-1.97	0.0487
Tennessee	1	-97.47677	7.99119	-12.2	<.0001
Texas	1	11.34351	11.37946	1	0.319
Virginia	1	12.49057	6.37002	1.96	0.0501
Piedmont	1	-10.56813	14.88474	-0.71	0.4778
West Gulf Coastal Plain	1	7.63189	11.21557	0.68	0.4963
Upper Coastal Plain	1	1.18474	14.55332	0.08	0.9351
Lower Coastal Plain	1	14.79675	13.96316	1.06	0.2895
Slash Pine	1	-75.99073	4.02875	-18.86	<.0001
Site Index	1	7.96446	0.11487	69.33	<.0001
Origin Density	1	-0.30251	0.00345	-87.78	<.0001
1st Thin	1	-161.09144	8.59631	-18.74	<.0001
Age of 1st Thin	1	5.21839	0.39793	13.11	<.0001

APPENDIX IX. Linear Regression: Risk Adjusted SEV at Typical (Age 35) Planted Stands, 0.04 Discount Rate, 2011 Prices

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	25	934396172	37375847	3675.56	<.0001
Error	3582	36424417	10169		
Corrected Total	3607	970820589			
Root MSE		100.84016	R-Square	0.9625	

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	-2054.79869	21.60746	-95.1	<.0001
Arkansas	1	96.32204	9.46114	10.18	<.0001
Florida	1	-66.47392	8.33074	-7.98	<.0001
Georgia	1	6.05814	7.61193	0.8	0.4262
Kentucky	1	96.32204	9.46114	10.18	<.0001
Louisiana	1	-54.82759	8.33074	-6.58	<.0001
Mississippi	1	-38.43829	8.33074	-4.61	<.0001
North Carolina	1	66.52715	7.61193	8.74	<.0001
Oklahoma	1	-17.29062	20.43088	-0.85	0.3974
South Carolina	1	-77.20931	7.61193	-10.14	<.0001
Tennessee	1	-768.43617	9.46114	-81.22	<.0001
Texas	1	62.51738	13.552	4.61	<.0001
Virginia	1	72.04519	7.61193	9.46	<.0001
Piedmont	1	466.80133	17.10214	27.29	<.0001
West Gulf Coastal Plain	1	398.85608	13.40584	29.75	<.0001
Upper Coastal Plain	1	524.83464	16.69236	31.44	<.0001
Lower Coastal Plain	1	431.13495	16.66696	25.87	<.0001
Slash Pine	1	-253.45724	4.87233	-52.02	<.0001
Site Index	1	36.88638	0.13774	267.81	<.0001
Origin Density	1	0.015	0.00997	1.5	0.1327
PCT	1	-212.48419	18.2893	-11.62	<.0001
1st Thin	1	253.27992	29.98518	8.45	<.0001
Age of PCT	1	12.49217	1.43764	8.69	<.0001
Density of PCT	1	0.01378	0.03301	0.42	0.6764
Age of 1st Thin	1	3.40204	1.67825	2.03	0.0427
Density of 1st Thin	1	-0.49536	0.0371	-13.35	<.0001

Note: PCT= pre-commercial thin

APPENDIX X. Linear Regression: Risk Adjusted SEV at Typical (Age 45) Natural Stands, 0.04 Discount Rate, 2011 Prices

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	21	45603999	2171619	1033.55	<.0001
Error	1454	3055031	2101.12148		
Corrected Total	1475	48659030			
Root MSE		45.83799	R-Square	0.9372	

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	-65.18909	15.97561	-4.08	<.0001
Arkansas	1	37.99725	6.77688	5.61	<.0001
Florida	1	-27.09228	5.89606	-4.59	<.0001
Georgia	1	2.44744	5.40206	0.45	0.6506
Kentucky	1	37.99725	6.77688	5.61	<.0001
Louisiana	1	-22.37313	5.89606	-3.79	0.0002
Mississippi	1	-15.73146	5.89606	-2.67	0.0077
North Carolina	1	26.87884	5.40206	4.98	<.0001
Oklahoma	1	-12.77407	14.48644	-0.88	0.378
South Carolina	1	-31.18792	5.40206	-5.77	<.0001
Tennessee	1	-304.15052	6.77688	-44.88	<.0001
Texas	1	27.43587	9.65029	2.84	0.0045
Virginia	1	29.10852	5.40206	5.39	<.0001
Piedmont	1	-12.14893	12.62292	-0.96	0.336
West Gulf Coastal Plain	1	7.63901	9.51131	0.8	0.422
Upper Coastal Plain	1	0.0005015	12.34187	0	1
Lower Coastal Plain	1	15.69708	11.84138	1.33	0.1852
Slash Pine	1	-70.53336	3.41656	-20.64	<.0001
Site Index	1	9.91919	0.09742	101.82	<.0001
Origin Density	1	-0.23989	0.00292	-82.08	<.0001
1st Thin	1	-192.65011	7.29005	-26.43	<.0001
Age of 1st Thin	1	7.44174	0.33746	22.05	<.0001

APPENDIX XI. Linear Regression: Risk Adjusted SEV at Optimal Planted Stands, 0.04 Discount Rate, 2011 Prices

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	25	1067854723	42714189	5124.14	<.0001
Error	3582	29859087	8335.87014		
Corrected Total	3607	1097713809			
Root MSE		91.30099	R-Square	0.9728	

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	-2201.75717	19.56346	-112.54	<.0001
Arkansas	1	86.0642	8.56615	10.05	<.0001
Florida	1	-48.3033	7.54268	-6.4	<.0001
Georgia	1	4.76342	6.89187	0.69	0.4895
Kentucky	1	86.0642	8.56615	10.05	<.0001
Louisiana	1	-40.09394	7.54268	-5.32	<.0001
Mississippi	1	-28.38391	7.54268	-3.76	0.0002
North Carolina	1	53.64022	6.89187	7.78	<.0001
Oklahoma	1	-7.78945	18.49818	-0.42	0.6737
South Carolina	1	-58.13336	6.89187	-8.44	<.0001
Tennessee	1	-422.61771	8.56615	-49.34	<.0001
Texas	1	48.22307	12.27002	3.93	<.0001
Virginia	1	58.23005	6.89187	8.45	<.0001
Piedmont	1	312.90996	15.48433	20.21	<.0001
West Gulf Coastal Plain	1	291.63518	12.13769	24.03	<.0001
Upper Coastal Plain	1	379.18473	15.11332	25.09	<.0001
Lower Coastal Plain	1	377.00775	15.09032	24.98	<.0001
Slash Pine	1	-237.25691	4.41142	-53.78	<.0001
Site Index	1	42.30766	0.12471	339.26	<.0001
Origin Density	1	-0.0121	0.00903	-1.34	0.1804
PCT	1	-236.16898	16.55919	-14.26	<.0001
1st Thin	1	166.38051	27.14867	6.13	<.0001
Age of PCT	1	10.78993	1.30165	8.29	<.0001
Density of PCT	1	0.02764	0.02989	0.92	0.3552
Age of 1st Thin	1	3.09913	1.51949	2.04	0.0415
Density of 1st Thin	1	-0.35688	0.03359	-10.62	<.0001

Note: PCT= pre-commercial thin

APPENDIX XII. Linear Regression: Risk Adjusted SEV at Optimal Natural Stands, 0.04 Discount Rate, 2011 Prices

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	21	84417495	4019881	1037.4	<.0001
Error	1454	5634189	3874.9582		
Corrected Total	1475	90051684			
Root MSE		62.24916	R-Square	0.9374	

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	205.6075	21.69528	9.48	<.0001
Arkansas	1	24.75398	9.20318	2.69	0.0072
Florida	1	-16.15012	8.007	-2.02	0.0439
Georgia	1	1.51405	7.33613	0.21	0.8365
Kentucky	1	24.75398	9.20318	2.69	0.0072
Louisiana	1	-13.38887	8.007	-1.67	0.0947
Mississippi	1	-9.46868	8.007	-1.18	0.2372
North Carolina	1	17.06412	7.33613	2.33	0.0202
Oklahoma	1	-7.36275	19.67296	-0.37	0.7083
South Carolina	1	-18.66144	7.33613	-2.54	0.0111
Tennessee	1	-143.6312	9.20318	-15.61	<.0001
Texas	1	17.35987	13.10534	1.32	0.1855
Virginia	1	18.52449	7.33613	2.53	0.0117
Piedmont	1	-22.95113	17.14225	-1.34	0.1808
West Gulf Coastal Plain	1	4.27279	12.9166	0.33	0.7408
Upper Coastal Plain	1	-8.5045	16.76057	-0.51	0.6119
Lower Coastal Plain	1	19.28757	16.0809	1.2	0.2306
Slash Pine	1	-84.08452	4.63978	-18.12	<.0001
Site Index	1	11.93986	0.1323	90.25	<.0001
Origin Density	1	-0.42788	0.00397	-107.81	<.0001
1st Thin	1	-313.10745	9.90008	-31.63	<.0001
Age of 1st Thin	1	11.11683	0.45828	24.26	<.0001

APPENDIX XIII. Linear Regression: Risk Adjusted SEV at Typical (Age 35) Planted Stands, 0.06 Discount Rate, 2011 Prices

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	25	188656818	7546273	3380.79	<.0001
Error	3582	7995386	2232.10099		
Corrected Total	3607	196652203			
Root MSE		47.24512	R-Square	0.9593	

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	-1001.7485	10.12342	-98.95	<.0001
Arkansas	1	44.20322	4.43269	9.97	<.0001
Florida	1	-30.34161	3.90308	-7.77	<.0001
Georgia	1	2.77369	3.5663	0.78	0.4368
Kentucky	1	44.20322	4.43269	9.97	<.0001
Louisiana	1	-25.04566	3.90308	-6.42	<.0001
Mississippi	1	-17.58171	3.90308	-4.5	<.0001
North Carolina	1	30.55618	3.5663	8.57	<.0001
Oklahoma	1	-8.28898	9.57217	-0.87	0.3866
South Carolina	1	-35.19598	3.5663	-9.87	<.0001
Tennessee	1	-338.43622	4.43269	-76.35	<.0001
Texas	1	28.85705	6.34932	4.54	<.0001
Virginia	1	33.10025	3.5663	9.28	<.0001
Piedmont	1	199.07227	8.01261	24.84	<.0001
West Gulf Coastal Plain	1	179.75608	6.28083	28.62	<.0001
Upper Coastal Plain	1	233.18976	7.82062	29.82	<.0001
Lower Coastal Plain	1	193.25377	7.80872	24.75	<.0001
Slash Pine	1	-112.14231	2.28276	-49.13	<.0001
Site Index	1	15.96019	0.06453	247.32	<.0001
Origin Density	1	-0.0067	0.00467	-1.43	0.1516
PCT	1	-146.72402	8.56881	-17.12	<.0001
1st Thin	1	207.36247	14.0485	14.76	<.0001
Age of PCT	1	9.18389	0.67356	13.63	<.0001
Density of PCT	1	-0.01802	0.01547	-1.17	0.2439
Age of 1st Thin	1	0.79196	0.78628	1.01	0.3139
Density of 1st Thin	1	-0.35127	0.01738	-20.21	<.0001

Note: PCT= pre-commercial thin

APPENDIX XIV. Linear Regression: Risk Adjusted SEV at Typical (Age 45) Natural Stands, 0.06 Discount Rate, 2011 Prices

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	21	6906958	328903	864.71	<.0001
Error	1454	553044	380.36033		
Corrected Total	1475	7460001			
Root MSE		19.50283	R-Square	0.9259	

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	-91.87774	6.79719	-13.52	<.0001
Arkansas	1	14.8453	2.88338	5.15	<.0001
Florida	1	-10.45865	2.50862	-4.17	<.0001
Georgia	1	0.95012	2.29843	0.41	0.6794
Kentucky	1	14.8453	2.88338	5.15	<.0001
Louisiana	1	-8.64487	2.50862	-3.45	0.0006
Mississippi	1	-6.08718	2.50862	-2.43	0.0154
North Carolina	1	10.47831	2.29843	4.56	<.0001
Oklahoma	1	-5.06201	6.16359	-0.82	0.4116
South Carolina	1	-12.03834	2.29843	-5.24	<.0001
Tennessee	1	-112.50078	2.88338	-39.02	<.0001
Texas	1	10.71527	4.10594	2.61	0.0092
Virginia	1	11.35185	2.29843	4.94	<.0001
Piedmont	1	-5.25362	5.37071	-0.98	0.3281
West Gulf Coastal Plain	1	8.80898	4.0468	2.18	0.0297
Upper Coastal Plain	1	5.64389	5.25113	1.07	0.2826
Lower Coastal Plain	1	12.21853	5.03819	2.43	0.0154
Slash Pine	1	-23.26381	1.45366	-16	<.0001
Site Index	1	3.84208	0.04145	92.7	<.0001
Origin Density	1	-0.09643	0.00124	-77.55	<.0001
1st Thin	1	-62.21152	3.10172	-20.06	<.0001
Age of 1st Thin	1	3.37038	0.14358	23.47	<.0001

APPENDIX XV. Linear Regression: Risk Adjusted SEV at Optimal Planted Stands, 0.06 Discount Rate, 2011 Prices

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	25	272930061	10917202	4987.54	<.0001
Error	3582	7840626	2188.89604		
Corrected Total	3607	280770686			
Root MSE		46.78564	R-Square	0.9721	

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	-1161.71555	10.02496	-115.88	<.0001
Arkansas	1	30.78231	4.38958	7.01	<.0001
Florida	1	-19.04273	3.86512	-4.93	<.0001
Georgia	1	1.81857	3.53162	0.51	0.6066
Kentucky	1	30.78231	4.38958	7.01	<.0001
Louisiana	1	-15.7938	3.86512	-4.09	<.0001
Mississippi	1	-11.17121	3.86512	-2.89	0.0039
North Carolina	1	20.61069	3.53162	5.84	<.0001
Oklahoma	1	-5.54513	9.47908	-0.58	0.5586
South Carolina	1	-22.24406	3.53162	-6.3	<.0001
Tennessee	1	-159.41694	4.38958	-36.32	<.0001
Texas	1	20.24554	6.28757	3.22	0.0013
Virginia	1	22.38061	3.53162	6.34	<.0001
Piedmont	1	109.91748	7.93468	13.85	<.0001
West Gulf Coastal Plain	1	136.26034	6.21975	21.91	<.0001
Upper Coastal Plain	1	155.88562	7.74456	20.13	<.0001
Lower Coastal Plain	1	194.76527	7.73278	25.19	<.0001
Slash Pine	1	-130.55541	2.26056	-57.75	<.0001
Site Index	1	21.16636	0.0639	331.22	<.0001
Origin Density	1	-0.03188	0.00463	-6.89	<.0001
PCT	1	-193.24047	8.48547	-22.77	<.0001
1st Thin	1	100.9287	13.91188	7.25	<.0001
Age of PCT	1	9.07062	0.66701	13.6	<.0001
Density of PCT	1	0.01999	0.01532	1.31	0.192
Age of 1st Thin	1	0.14353	0.77864	0.18	0.8538
Density of 1st Thin	1	-0.16346	0.01721	-9.5	<.0001

Note: PCT= pre-commercial thin

APPENDIX XVI. Linear Regression: Risk Adjusted SEV at Optimal Natural Stands, 0.06 Discount Rate, 2011 Prices

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	21	21516602	1024600	1006.26	<.0001
Error	1454	1480507	1018.23006		
Corrected Total	1475	22997109			
Root MSE		31.90972	R-Square	0.9356	

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	83.24001	11.12128	7.48	<.0001
Arkansas	1	10.09336	4.71767	2.14	0.0326
Florida	1	-6.87315	4.10449	-1.67	0.0942
Georgia	1	0.63556	3.7606	0.17	0.8658
Kentucky	1	10.09336	4.71767	2.14	0.0326
Louisiana	1	-5.70194	4.10449	-1.39	0.165
Mississippi	1	-4.03503	4.10449	-0.98	0.3257
North Carolina	1	7.11788	3.7606	1.89	0.0586
Oklahoma	1	-3.49733	10.08461	-0.35	0.7288
South Carolina	1	-7.8832	3.7606	-2.1	0.0362
Tennessee	1	-62.28608	4.71767	-13.2	<.0001
Texas	1	7.32737	6.71796	1.09	0.2756
Virginia	1	7.72203	3.7606	2.05	0.0402
Piedmont	1	-12.62507	8.78734	-1.44	0.151
West Gulf Coastal Plain	1	6.71163	6.62121	1.01	0.3109
Upper Coastal Plain	1	0.01806	8.59168	0	0.9983
Lower Coastal Plain	1	14.73655	8.24327	1.79	0.074
Slash Pine	1	-36.7405	2.37841	-15.45	<.0001
Site Index	1	5.70714	0.06782	84.16	<.0001
Origin Density	1	-0.22917	0.00203	-112.64	<.0001
1st Thin	1	-128.8362	5.07491	-25.39	<.0001
Age of 1st Thin	1	4.73957	0.23492	20.18	<.0001

APPENDIX XVII. Parameter Estimates for Planted Stands

Stand Origin	Planted	Planted	Planted	Planted	Planted	Planted	Planted	Planted
Discount Rate	0.04	0.06	0.04	0.06	0.04	0.06	0.04	0.06
Price Year	2005	2005	2011	2011	2005	2005	2011	2011
Risk Adjusted SEV Model	Typical (age 35)	Typical (age 35)	Typical (age 35)	Typical (age 35)	Optimal	Optimal	Optimal	Optimal
Mean	1479	503	830	227	1606	646	933	343
Intercept	-3262	-1515	-2055	-1002	-3568	-1843	-2202	-1162
Arkansas	151	69	96	44	143	53	86	31
Florida	-104	-47	-66	-30	-82	-33	-48	-19
Georgia	9	4	6	3	8	3	5	2
Kentucky	151	69	96	44	143	53	86	31
Louisiana	-85	-39	-55	-25	-68	-27	-40	-16
Mississippi	-60	-27	-38	-18	-48	-19	-28	-11
North Carolina	104	47	67	31	90	35	54	21
Oklahoma	-22	-10	-17	-8	-5	-6	-8	-6
South Carolina	-121	-54	-77	-35	-98	-38	-58	-22
Tennessee	-1205	-526	-768	-338	-758	-294	-423	-159
Texas	97	44	63	29	83	34	48	20
Virginia	113	51	72	33	97	38	58	22
Piedmont	791	337	467	199	623	229	313	110
West Gulf Coastal Plain	660	291	399	180	522	225	292	136
Upper Coastal Plain	875	382	525	233	716	287	379	156
Lower Coastal Plain	709	311	431	193	643	312	377	195
Slash Pine	-379	-166	-253	-112	-325	-167	-237	-131
Site Index	60	26	37	16	68	34	42	21
Origin Density	-0.01	-0.02	0.02	-0.01	-0.06	-0.07	-0.01	-0.03
PCT	-205	-143	-212	-147	-153	-102	-236	-193
1st Thin	275	217	253	207	258	200	166	101
Age of PCT	16	11	12	9	13	9	11	9
Density of PCT	-0.01	-0.03	0.01	-0.02	-0.08	-0.1	0.03	0.2
Age of 1st Thin	1.3	-0.11	3.4	0.79	-0.3	-2.45	3.1	1.4
Density of 1st Thin	-0.52	-0.36	-0.5	-0.35	-0.5	-0.31	-0.36	-0.16

Note: SEV= soil expectation value; PCT= pre-commercial thin

APPENDIX XVIII. Parameter Estimates for Natural Stands

Stand Origin	Natural	Natural	Natural	Natural	Natural	Natural	Natural	Natural
Discount Rate	0.04	0.06	0.04	0.06	0.04	0.06	0.04	0.06
Price Year	2005	2005	2011	2011	2005	2005	2011	2011
Risk Adjusted SEV Model	Typical (age 45)	Typical (age 45)	Typical (age 45)	Typical (age 45)	Optimal	Optimal	Optimal	Optimal
Mean	549	158	356	89	626	234	482	190
Intercept	-70	-94	-65	-92	140	76	206	83
Arkansas	58	23	38	15	47	17	25	10
Florida	-41	-16	-27	-10	-31	-11	-16	-7
Georgia	4	1	2	1	3	1	2	1
Kentucky	58	23	38	15	47	17	25	10
Louisiana	-34	-13	-22	-9	-26	-9	-13	-6
Mississippi	-24	-9	-16	-6	-18	-6	-9	-4
North Carolina	41	16	27	10	33	12	17	7
Oklahoma	-18	-7	-13	-5	-15	-4	-7	-3
South Carolina	-47	-18	-31	-12	-36	-13	-19	-8
Tennessee	-465	-171	-304	-113	-259	-97	-144	-62
Texas	41	16	27	11	34	11	17	7
Virginia	44	17	29	11	35	12	19	8
Piedmont	-14	-6	-12	-5	-21	-11	-23	-13
West Gulf Coastal Plain	8	9	8	9	4	8	4	7
Upper Coastal Plain	-2	5	0	6	-8	1	-9	0
Lower Coastal Plain	18	13	16	12	18	15	19	15
Slash Pine	-128	-44	-71	-23	-178	-76	-84	-37
Site Index	16	6	10	4	18	8	12	6
Origin Density	-0.4	-0.15	-0.24	-0.1	-0.57	-0.3	-0.43	-0.23
1st Thin	-234	-77	-193	-62	-344	-161	-313	-129
Age of 1st Thin	6	3	7	3	9	5	11	5

Note: SEV= soil expectation value