Silvopasture Establishment and Economics: Modeling the Cost of Wildlife Browse Damage to Stand Establishment and Cattle Introduction on Redstone Arsenal

by

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A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
December 8, 2012

Keywords: Alabama, economics, replacement cost approach, silvopasture, wildlife damage

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Abstract

This thesis examines three distinct but related aspects of wildlife browse damage to southern yellow pine establishment and growth in a silvopasture: the characteristics and extent of wildlife browse damage to 1-year old loblolly seedlings, seedling mortality and growth rate over the second growing season, and estimates of potential economic trade-offs among tree and livestock values for introducing cattle after the third growing season. Study sites were located at Redstone Arsenal in north-central Alabama. The individual heights and damage conditions of loblolly seedlings were measured across the second growing season during five bi-monthly data collection periods that began in March of 2011 and ended in November of 2011. Results suggest a significant association between wildlife browse damage to terminal buds on 1-year old seedlings and the 18 inch average height reduction observed for 2-year old seedlings when compared to undamaged loblolly in the same silvopasture. Seedling growth and economic models suggest average seedling at the end of the third growing season, combined with initial seedling mortality, may warrant the decision to postpone cattle introduction due to the potential loss in tree value and the alternative of hay-lease revenue. This research provides information and decision tools to assist Redstone Arsenal's resource managers and Alabama's landowners in assessing ecological and economic interactions between silvopasture components. This information is important for a range of stakeholders during the planning and budgeting of a silvopasture whether expanding a current operation, transitioning from traditional agriculture, or obtaining a capital investment to begin an operation.

Acknowledgments

I thank the United States Army personnel at Redstone Arsenal for providing the study area and logistical support. I extend a special thanks to my committee and many others who so graciously expended energy/mass through various levels of resistance over great distances of space/time (force/work done) to assist in the completion of this research: Becky Barlow, James Armstrong, Charles Monks, Kevin Guthrie, Brent Williams, Holly Jantz, Patti Staudenmaier, Charlesa Paris, Lee Paris, Nathan Paris, Kyle Paris, John Kush, John Gilbert, David Laband, Emily Stutzman, Iva B. Moore, Grover C. Moore II, and Grover C. Moore III. I am forever grateful. An investment in knowledge truly pays the best interest.

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CHAPTER 1

INTRODUCTION

According to estimates made by the Massachusetts Institute for Technology (MIT) Joint Program on the Science and Policy of Global Change, the global human population will approach 9 billion people by the year 2050, approximately doubling the 2010 levels of global food and energy consumption (Reilly and Paltsev 2007; Prinn and Reilly 2012). Furthermore, technological advances in electronics and paper recycling, changing land-use patterns and increasing environmental degradation have made it more difficult for traditional agricultural and forestry practices to supply these growing demands while remaining economically and ecologically viable (USDA National Agroforestry Center 2008; USDA-ERS 2010; World Agroforestry Center 2010). In Alabama for example, the United States Department of Agriculture's Economic Research Service (USDA-ERS) estimates that from 1978 to 2009, the number of small farms in Alabama declined by approximately 25% (Workman 2003; USDA-ERS 2010). Furthermore, between the years 1978 and 2009, it is estimated that the number of farm operators under the age of 34 decreased by 40% while operators over 70 years of age increased by 20% during that same period (USDA-ERS 2010).

As of 2010, 92% of Alabama's farms were less than 500 acres in size, with 60% being less than 100 acres (USDA-ERS 2010). Similarly, approximately 65% of Alabama's forestland was comprised of privately owned, non-industrial properties that were less than 500 acres in total area (USDA-ERS 2010). Combined, agricultural and forest products industries accounted for approximately 25% of all jobs in Alabama (USDA-ERS 2010). However, the annual rate of unemployment these industries from 2008 to 2011 was 6.1%, 11.9%, 10.8%, and 10.1% respectively (USDA-ERS 2012). As a result, individuals and organizations throughout the state were searching for new opportunities and methods with which to generate additional and diversified income from their lands (Workman 2003; Nowak and Walton 2005; USDA-ERS 2012).

Concurrently, more than 30 years of research suggest that the agroforestry techniques of alley-cropping, forest farming, riparian buffers, silvopasture, and wind-breaks have the potential to generate additional income and improve environmental sustainability by systematically integrating the production of crops and trees on the same parcel of land (Clason 1995; Grado et al. 2001; Husak and Grado 2002; USDA National Agroforestry Center 2008; Hamilton 2008; USDA National Agroforestry Center 2010; World Agroforestry Center 2010). As part of an overall land management strategy, agroforestry practices have the ability to generate annual and periodic revenues beyond that of traditional land management practices (Clason 1995; Husak and Grado 2002). In addition to improved financial performance, agroforestry practices can produce ecological benefits such as the improvement of wildlife habitat, reduction of soil erosion, and increased bio-diversity (Sharrow et al. 2009; Frey et al. 2010). The potential for increased economic and ecological benefits have attracted the attention of various individual and organizational stakeholders including the U.S. Secretary of Agriculture, who in June of 2011 announced that efforts were underway to implement a nation-wide agroforestry extension community (Sorrow 2011; USDA 2011).

Furthermore, agroforestry had attracted interest from the United States Army at the Redstone Arsenal (RSA) instillation in Madison County, Alabama. The total land area occupied by RSA is approximately 38,100 acres (59.53 mi²) and is positioned on the southwest side of Huntsville, Alabama. RSA is home to the Marshall Space Flight Center and U.S. Missile Defense Command. It is comprised of diverse landscapes that range from upland pine forest and bottomland hardwood swamps to stands of planted pine and open pasture land. The Arsenal's management plan is focused on a sustainable, ecosystem approach but historically does include practices which are used to generate financial returns for the installation.

According to resource managers at Redstone, approximately 2,000 acres of pastureland are under cattle grazing contracts with private individuals, with another 1,500 acres being suitable for cattle grazing. Due to a variety of economic pressures, RSA managers have been searching for innovative and sustainable techniques that can increase and diversify revenue streams yet enhance ecological sustainability. As a result of these pressures, in December of 2009 a limited area of land was set aside for the purpose of testing the practice of silvopasture in order to assess the feasibility of expanding its use.

Of the five agroforestry practices, silvopasture has become the most common in the southeastern United States (Sharrow 2001; Workman 2003; Hamilton 2008). Silvopasture integrates the production of timber, forage and livestock on the same land-unit (Stainback and Alavalapati 2004; Hamilton 2008; Oswald et al. 2008; Sharrow et al. 2009). Silvopasture is used to produce high-value timber products, such as saw-timber and veneer-logs, while generating short-term cash flow from the sale of livestock and other products such as hay and pine-straw (Stainback and Alavalapati 2004; Alavalapati and Mercer 2005; Hamilton 2008). This integration of components is designed to optimize the production of multiple components in contrast to “maximizing” the production of any single component (Stainback and Alavalapati 2004; Hamilton 2008; Bambo et al. 2009).

In the southeastern U.S., yellow-pines such as loblolly (*Pinus taeda*), slash (*Pinus elliottii*), and longleaf (*Pinus palustris*) may be used as the timber component of a silvopasture system and can be established on existing pasture land by planting single, double, or triple row trees while leaving wide, unplanted corridors between them (Lewis 1984; Clason 1995; Kush et al. 2004; Hamilton 2008; Sharrow et al. 2009). Pine silvopasture may also be established by thinning existing stands of timber in such a manner as to mimic the row and corridor configurations as described for planting trees in open pasture (Sharrow and Fletcher 2003; Hamilton 2008). Thinning trees to these conditions is required to reduce canopy cover for adequate sunlight to reach the forest floor which allows for the production of forage (Hamilton 2008; Nowak et al. 2009). Each of the tree arrangements has relative advantages and disadvantages, but they must be balanced with considerations for producing adequate forage (Hamilton 2008).

The forage component of a silvopasture can include various mixtures of warm- and/or cool- season legumes and grasses to be used as hay or food for livestock (Hamilton 2008; Garret 2009; Nowak et al. 2009). The establishment and production of forage in silvopasture is similar to that of traditional pasture management but is different in that the selected forage species should be more shade tolerant. Suitable cool season legumes include various species of clover (*Trifolium spp.*) and vetch (*Vicia spp.*) while grasses including rye-grass (*Lolium spp.*) or native species such as little bluestem (*Schizachyrium scoparium*) and eastern gammagrass (*Tripsacum dactaloides*) are viable choices for the warm-season (Hamilton 2008). Likewise, the livestock component may be selected from a range grazing animals including domestic cattle (*Bos taurus*), domestic goats (*Capra hircus*), or domestic sheep (*Ovis aries*) (Hamilton 2008; Garret 2009). However, landowners are cautioned by the USDA - National Agroforestry Center (USDA-NAC) to be aware of the fact that livestock can damage young seedlings by browsing, trampling, and rubbing them during the first 3 to 4 years from establishment and thus recommend that landowners delay livestock introduction during that time (Hamilton 2008; Brauer et al. 2009).

According to the recommendation in Hamilton (2008), the approximate time range of 3 to 4 years are required for southern yellow pine to reach the height range of 5 to 6 feet where seedlings are large enough to withstand interaction with livestock (Hamilton 2008). The first 3 to 4 years of silvopasture system establishment represents an important and financially sensitive time period for many landowners because they postponing livestock from a young silvopasture means that stakeholders must forgo vital cash-flows from livestock operations (Kinicki and Williams 2006; Godsey 2007; Plunkett et al. 2007; Godsey et al. 2009). Accordingly, studies have addressed these concerns and have suggested that landowners may offset forgone livestock revenue by producing hay or row-crops in the silvopasture's wide alleyways while waiting on the trees to mature (Husak and Grado 2002; Hamilton 2008).

Once livestock are introduced, use of an internal fencing system and rotational grazing strategy are vital to maintaining a sufficient supply of high-quality forage, especially when silvopastures are implemented on relatively small tracts of land (Lewis et al.1984; Fike et al. 2004; Hamilton 2008). Therefore it is recommended that the total silvopasture acreage be divided or sectioned into approximately equal size paddocks, forage growth should be closely monitored, and livestock rotated systematically through each paddock thereby avoiding over-grazing in any single paddock-unit (Lewis et al. 1984; Hamilton 2008; Brauer et al. 2009). The ideal outcome of the rotational grazing strategy is that the livestock are rotated in such a manner that the forage within each paddock is allowed sufficient time to recover before one rotational cycle is completed, thus allowing the landowner to produce a sustainable loop of forage production (Lewis et al. 1984; Hamilton 2008).

As trees continue to mature over time they provide shade for livestock, which research suggests can improve livestock profitability (Lewis et al. 1984; Garret et al. 2004; Hamilton 2008; Godsey et al. 2009). Tree shade can benefit livestock mainly by providing a temperature buffer for both the animals and their forage (Lewis et al. 1984; Garret et al. 2004; Hamilton 2008). By buffering animals and forage from heat, thermo-equilibrium in the animals is more easily regulated, and forage transpiration rates are reduced thereby reducing loss of water and nutrient content (Lewis et al. 1984; Garret et al. 2004; Hamilton 2008). As a result, trees can reduce livestock production costs associated with water and supplemental feed for the animals and fertilization requirements for their forage (Lewis et al. 1984; Hamilton 2008).

Understanding the establishment and importance of the timber component is imperative because economic research suggests that as trees in a silvopasture mature they can produce financial benefits not only from timber sales and reduced production costs for livestock but from the ecological and wildlife benefits as well (Husak and Grado 2002; Fike et al. 2004; Rollins et al. 2004; Lemus 2009). These studies suggest that as the trees in a silvopasture mature, they produce additional financial benefits from annual tax incentives, payments from cost-share programs such as the Conservation Reserve Program (CRP) and Wildlife Habitat Incentive Program (WHIP), and annual income from the potential to incorporate hunting leases (Husak and Grado 2002; Gurevitch et al. 2006; Godsey 2007; Lemus 2009). In many cases, the practice of silvopasture can improve wildlife habitat and attract species such as wild-turkey (*Meliagris gallapavo*), white-tailed deer (*Odocoileus virginianus*), and rabbits (*Sylvilagus spp.*) by increasing the availability, diversity, and quality of seasonal resources (Grado et al. 2001; Nowak et al. 2008; Robinson 2005; USDA-NRCS 2009).

Although both stakeholders and wildlife can benefit from silvopastures, the ability of a pine silvopasture to attract wildlife also creates the potential for wildlife-related damages to the tree component, which ultimately could reduce the system's financial performance (Dickson 2001; Conover 2002; Sharrow and Fletcher 2003). According to Sharrow (2001) and Sharrow and Fletcher (2003), although silvopasture managers may harvest hay for the first 3 to 4 years while waiting to introduce livestock, that approach does not avoid threats posed by wild populations of deer and rabbits. However, little has been written about this potential threat (Sharrow and Fletcher 2003). Moreover, the lack of information regarding deer damage in silvopasture may be linked to the relatively recent increase in deer populations. After having been drastically reduced in numbers during the 19^{th} and early 20^{th} centuries, deer populations have now rebounded across the southeast and have exponentially increased over the past 30 years; the same time-span during which much of the research on silvopasture establishment and management has been conducted (Dickson 2001; Conover 2002; Hamilton 2008).

With regards to traditional forestry and agricultural practices, deer are known to cause severe damage to orchards, nurseries, ornamental trees, and shrubs (Semans and Helon 2008). In the United States for example, wildlife professionals estimate that the annual cost of deer damage to timber and agricultural productivity is approximately $750 and $500 million dollars respectively (Waller and Alverson 1997; Conover 2002; Seamans and Helon 2008). Therefore, the potential impact of large deer populations may deserve consideration by those considering the establishment of a silvopasture in those areas.

The state of Alabama, for example, has a large deer population that is estimated to contain more than 1.8 million animals (Cook and Gray 2003; USDA-APHIS 2010). The state's large deer population is of significant interest not just because they can cause damage but because, similar to cattle, they are relatively long-lived, ruminants that have been known to cause localized plant extinctions, especially when populations are close or above the carrying capacity of the habitat (Miller and Marchinton 1995; Waller and Alverson 1997; Dickson 2001; Conover 2002). According to Campbell (1976), when deer populations approach carrying capacity of the land they can become "nutritionally stressed", and when that happens, they begin browsing a wider range of plants and damage to young southern pines can be severe.

Likewise, rabbits (*Sylvilagus spp.*) may be able to impact the timber component of a silvopasture, but like with deer, there is limited quantitative data pertaining to the extent and effects of rabbit damage to southern pine (Hunt 1968; Shelton and Cain 2002). Rabbits, unlike deer, are short-lived herbivores, with populations experiencing an annual mortality rate of 80% to 90% (Dickson 2001). Annual rabbit populations fluctuate widely due both to climate effects on food items like grasses and forbs, and also because rabbits are prey for a wide range of animals including coyotes (*Canis* latrans), gray fox (*Urocyon cinereoargenteus*), and great horned owls (*Bubo virginianus*). Although data are limited, a few studies, involving the management of traditional loblolly pine-plantations in the southeastern United States, have observed that browse damage by rabbits can reduce the annual growth of loblolly seedlings by up to 40% when compared to undamaged seedlings (Hunt 1968; Wakeley 1970; Shelton and Cain 2002).

Additionally, these studies agree that damage to the terminal bud and main stem of southern pine can reduce or halt seedling growth during the first 4 to 5 years after planting (Hunt

1968; Wakeley 1970; Campbell 1976; Shelton and Cain 2002). Reduced or halted pine seedling growth during the first 4 to 5 years is directly relative to silvopasture because regardless of damage to seedlings the landowner is not generating cash flow from livestock sales while they must wait 3 to 4 years until seedlings reach 5 to 6 feet in height (Pearson 1984; Sharrow and Fletcher 2003; Hamilton 2008; Brauer et al. 2009; Godsey et al. 2009). Taking note of this general recommendation may also be important because there can be conflicting recommendations regarding when cattle (livestock) should be introduced to southern pine silvopastures.

Grado et al. (2001) conducted a well-known economic analysis of hypothetical silvopasture in Mississippi to which cattle were introduced two years after loblolly pine were established. In contrast to the recommended minimum tree height of 5 to 6 feet in Hamilton (2008), Grado et al. (2001) stated that cattle were demonstrated to have had no impact on loblolly pine after seedlings reached 18 inches in height. Furthermore, unlike both Hamilton (2008) and Grado et al. (2001), Pearson (1984) discussed considerations for silvopasture management and suggested that cattle grazing should not commence until pine seedlings have reached a minimum height range of 7 to 10 feet based on experience gained from grazing cattle in naturally regenerated southern pine stands. Please note that although an older study, Pearson (1984) specifically referenced 7 to 10 feet for southern pine when grazing "cattle", in contrast Grado et al. (2001) specifically referenced 18 inches for southern pine when grazing "cattle", and Hamilton (2008) referenced 5 to 6 feet for southern pine when grazing "livestock" in general.

What is clear is that the literature regarding silvopasture establishment and management supports the concept that 1) all "livestock" species which are compatible for silvopasture management can damage young pine seedlings if grazing is begun too soon, 2) southern yellow pine must reach some minimum height ranging from 18 inches to 10 feet in order to reduce the probability that livestock could severely damage the terminal bud and main stem of young trees through browsing, rubbing, and trampling, and 3) all grazing by all livestock species should be postponed for 2 to 4 years to avoid a relative loss of trees and the expected benefits produced by this major system component (Lewis et al. 1984; Pearson et al. 1984; Clason 1995; Grado et al. 2001; Husak and Grado 2002; Garret et al. 2004; Godsey 2007; Hamilton 2008). Furthermore, although never before studied in a southern pine silvopasture, the literature regarding wildlife biology and damage management has established that deer and rabbit browse damage can reduce the growth of southern yellow pine for up to 4 to 5 years after establishment. Concurrently, it suggests there is a gap in the literature on pine-based silvopasture management in the southeastern U.S.

From this it follows that browse damage by rabbits and deer has the potential to reduce pine seedling growth during a critical financial period of silvopasture establishment and thereby alter the timing critical cash-flows or reduce tree asset value. The former and latter impacts could be the result of two scenarios. First, wildlife browse damage could impact silvopasture establishment by if the damage reduced tree growth such that the landowner postponed livestock (and livestock revenue) for an additional year to avoid further tree damage caused by livestock. Second, because cash-flow is important to young business ventures, the landowner who cannot afford to postpone livestock for a year longer than was originally planned, introduces livestock which then cause critical damage to a significant portion of young trees because they are too small. Although hay or row-row crops may be harvested from alleyways to supplement livestock revenue during the first 3 to 4 years, there exists an additional level of uncertainty regarding the impact of wildlife damage, livestock damage, or the combination of wildlife and livestock damage to the quality and financial benefits of the tree component.

The ability of the timber component to establish and grow is important. It is important because once trees are tall enough, landowners may introduce livestock. However, tree establishment and growth is important because trees in a silvopasture will produce shade for livestock (reduced heat stress and production costs), habitat for wildlife (cost-share programs; hunting leases), and eventually merchantable timber. However, because the aforementioned benefits are some of the key drivers of silvopasture success, the potential financial impact of wildlife browse damage to silvopasture systems is uncertain. It is therefore desirable to have trees establish, survive and grow unhindered in a silvopasture so that there is less risk of damage caused by livestock introduction.

Additionally, reducing tree damage caused by wildlife and livestock are important so that stakeholders have the opportunity to realize more of the benefits that the trees in a silvopasture can produce. Silvopastures can provide numerous market and non-market benefits however, like other agricultural and timber management practices, productive resources including land, labor and capital are limited, thus trade-offs are certain (Godsey et al. 2009; Zhang and Pearse 2011). The process of evaluating the total costs and benefits of any land management practice is difficult and never precise, but proper planning, budgeting, and valuation are essential to provide guidelines for ranking management decisions (Godsey 2007; Godsey et al. 2009; Zhang and Pearse 2011). Therefore it is important to understand how wildlife browse damage may influence tree establishment and livestock introduction to a silvopasture system.

As previously mentioned, in December of 2009, the United States Army at Redstone Arsenal (RSA) implemented a limited area of loblolly pine silvopasture and is assessing the feasibility of expanding its use. In December of 2010, after an assessment of the 1 year-old loblolly pine seedlings, RSA personnel reported the existence of wildlife browse damage. According to RSA managers, once seedlings have reached sufficient size, cattle grazing leases (similar to those which they currently use on open pastureland) may be incorporated in order to further assess timber and livestock component performance. This makes this Redstone Arsenal an ideal location for research to examine the impact of wildlife browse damage on the growth of loblolly pine seedlings in a silvopasture system. For example, this research could generate valuable information for managers at Redstone Arsenal in their commitment to sustainable resource management.

This thesis examines three distinct but related aspects of wildlife browse damage to southern yellow pine establishment and growth in a silvopasture: 1) the characteristics and extent of wildlife browse damage to 1-year old loblolly seedlings, 2) seedling mortality and growth over the 2nd year, and 3) estimates of potential economic trade-offs among tree and livestock values for introducing cattle in the 3rd year. This research can provide valuable information needed to help fill the existing knowledge gap regarding pine silvopasture establishment in Alabama and needs of future research. Moreover, this research can provide information and decision tools to assist Alabama's forest and farm owners in assessing relationships among silvopasture components and influences on the timing of cash-flows (Godsey 2007; ACES 2011). This would be important for a range of stakeholders, whether he or she is considering the expansion of current operations, the transition from traditional agriculture and forestry to silvopasture, or to an individual and/or cooperative seeking a loan in order establish an operation (Godsey 2007; Hamilton 2008; Godsey et al. 2009).

1. Chapter 2 presents an overview of the existing literature on silvopasture establishment, wildlife damage management, financial metrics, and economic considerations for silvopasture management. This chapter explores and explains the interconnectedness of these biological and economic issues, and establishes the biological foundation and economic framework on which the components of this study can be evaluated.
2. Chapter 3 examines four silvopastures located on Redstone Arsenal. This chapter addresses the primary research question: can wildlife browse damage to seedlings in a pine based silvopasture impact the timber component and value in such a way as to cause the delay of livestock introduction thereby impacting critical management decisions? This chapter begins by briefly introducing the topic of research interest and describes the physiographic characteristics of the study area as well as on-site descriptions of the silvopasture area on Redstone Arsenal. This chapter also describes the methods and criteria used for assessing and analyzing the biological and economic characteristics of seedling damage. Results are presented and discussed.
3. Chapter 3 also discusses the benefits, implications and limitations of this research for silvopasture management. This chapter explains how the results of this research can be utilized by Redstone Arsenal, small-scale farmers and landowners, and other stakeholder objectives. The limits of this study and its results are presented and this chapter concludes by describing the need for additional research issues related to the economics of wildlife, animal and other organism damage in pine based silvopastures.

CHAPTER 2

LITERATURE REVIEW

According to the United States Department of Agriculture (USDA 2011), agroforestry has garnered increased attention among various U.S. government organizations for its potential role in helping to meet increasing global demands on both farm and forest lands (Sorrow 2011). In addition, the MIT Center for Energy and Environmental Policy Research, by the year 2050 global demand for food and energy will be approximately double the amounts consumed in 2010 (Nowak and Walton 2005; Reilly and Paltsev 2007; Prinn and Reilly 2012; Susaeta et al. 2012). Together, research suggests that the increased demand for food and energy will require organizations, producers and consumers to adapt and utilize multi-functional agricultural and forest systems on a scale as never before seen (Reilly and Paltsev 2007; Prinn and Reilly 2012; Susaeta et al. 2012).

2.1. Agroforestry: Supplying Demand

Conversely, many believe that the multi-functional agroforestry practices of alley-cropping, forest-farming, riparian buffers, silvopasture, and wind-breaks have the potential to significantly increase farm and forest land-use efficiency (Clason 1995; Hamilton 2008; Sharrow et al. 2009). In contrast to many traditional management techniques, agroforestry practices improve efficiency by systematically producing multiple goods and services on the same land-unit (Hamilton 2008; Godsey et al. 2009; World Agroforestry Center 2010). The use of agroforestry techniques has increased in the last 30 years, and as a result many public and private organizations are investigating the potential of agroforestry systems in the U.S. South (Sharrow 2001; Susaeta et al. 2012).

2.2. Silvopasture: an Agroforestry Practice

Of the five agroforestry practices, silvopasture has become the most common practice in the southeastern United States (Sharrow 2001; Hamilton 2008). Silvopasture integrates livestock, forage production and forestry on the same land-unit (Hamilton 2008; Oswald et al. 2008; Sharrow et al. 2009). Silvopasture is used to produce high-value timber products, such as saw-timber and veneer-logs, while generating short-term cash-flows from the sale of livestock and other products such as hay and pine-straw (Hamilton 2008). Figure 2.1 illustrates the results of a financial analysis conducted by Grado et al. (2001) in which a pine based silvopasture produces a higher rate of return (ROR) on investment than does a traditional pine-plantation or pasture cattle grazing operation (Hamilton 2008).

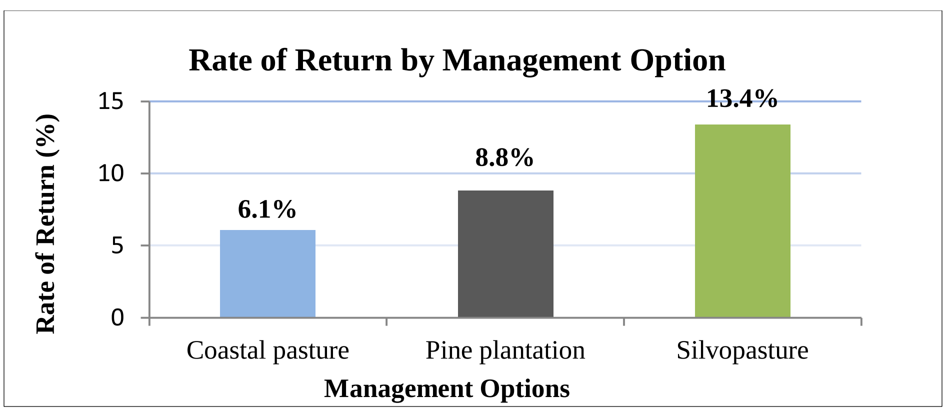

Figure 2.1. Rate of return (ROR) comparison for an investment in pine based silvopasture, traditional pine-plantation, and pasture/cattle-grazing operation.

In the southeastern U.S., yellow-pines such as loblolly, and slash, and longleaf may be used as the timber component of a silvopasture system (Kush et al. 2004; Hamilton 2008; Oswald et al. 2008). Pine silvopastures can be established on afforested tracts or by thinning existing timber stands (Hamilton 2008). Typically, silvopasture have been established on afforested tracts, such as existing pasture land, by planting single or double rows of trees while leaving wide, unplanted corridors between them (Hamilton 2008; Sharrow et al. 2009). Leaving wide corridors or alleyways between tree rows means that a silvopasture utilizes a lower initial stocking that can range from approximately 200 - 400 trees per acre in contrast to approximately 500 - 800 trees per acre in a traditional pine plantation (Shelton and Cain 2002; Brauer et al. 2009).

Using the double-row silvopasture arrangement as an example, 350-450 seedlings may be planted in a 6’x6’x35’, a 6’x8’x40’, or 8’x8’x40’ spacing arrangement (Hamilton 2008; Long 2003). A double-row silvopasture with a 6’x8’x40’ spacing arrangement means that seedlings along the length of a single row are separated by six feet (6’), eight feet (8’) separates rows and unplanted corridors of forty feet (40’) in width separate each double-row set of trees (Hamilton 2008). Figure 2.1 comes from Hamilton (2008) and shows an example of how the spacing between individual trees, tree rows, and alleyways may be altered to work within the landowner’s objectives for timber and forage production and environmental benefits such as wildlife habitat (Grado et al. 2001; Hamilton 2008).

Pine silvopasture may also be established by thinning existing stands of timber in such a manner as to mimic the row and corridor configurations as described for planting trees in open pasture (Sharrow and Fletcher 2003; Hamilton 2008). Thinning trees to these conditions is required to reduce canopy cover in order allow adequate sunlight to reach the forest floor to stimulate forage production as well as provide the landowner with some initial revenue (Hamilton 2008; Nowak et al. 2009). Each of the silvopasture tree arrangements will have relative advantages and disadvantages based on factors such as landowner objectives, site characteristics, tree stocking and tree arrangement but considerations for timber production must be balanced with those for forage and livestock production (Hamilton 2008; Garret 2009; Garret et al. 2009; Klopfenstein 2010).

The forage component of a silvopasture can include various mixtures of warm- and/or cool- season legumes and grasses to be used as hay or food for livestock (Hamilton 2008). The establishment and production of forage in silvopasture is similar to that of traditional pasture management according to Hamilton (2008), but is different in that the selected forage species should be more shade tolerant. According to Hamilton (2008), suitable forage legumes include various species of clover (*Trifolium spp.*) and vetch (*Vicia spp.)* while grasses may include rye-grass (*Lolium spp.*) or native species such as little bluestem (*Schizachyrium scoparium*) and eastern gammagrass (*Tripsacum dactaloides*).

Likewise, the livestock component may be selected from a range grazing animals including domestic cattle (*Bos taurus*), domestic goats (*Capra hircus*), or domestic sheep (*Ovis aries*) (Garret 2009; Sharrow et al.2009). Please note that livestock can damage young seedlings by browsing, trampling, and rubbing them during the first 3 - 4 years from establishment (Lewis et al. 1984; Hamilton 2008). Accordingly, the United States Department of Agriculture’s National Agroforestry Center (USDA-NAC) recommends that when landowners establish a pine silvopasture on non-forested tracts, livestock grazing should be delayed for approximately 3 - 4 years (Hamilton 2008). According to this recommendation, 3-4 years are required for species of southern yellow pine to reach 5 to 6 feet in height and thus avoid being damaged by livestock (Hamilton 2008). Once livestock are introduced, use of a rotational grazing strategy is vital to maintaining a sufficient supply of high-quality forage, especially when silvopastures are implemented on relatively small tracts of land (Lewis et al. 1984; Hamilton 2008).

Therefore it is recommended that the total silvopasture acreage be divided or sectioned into approximately equal size paddocks (Lewis et al. 1984; Hamilton 2008). Combined with the close monitoring of forage performance, livestock are systematically rotated through each paddock so that livestock spend a limited amount of time in each paddock thereby reducing the probability that the forage will be over-grazed in any single paddock-unit (Hamilton 2008). The ideal outcome of the rotational grazing strategy is that the livestock are rotated in such a manner that the forage within each paddock is allowed sufficient time to recover before one rotation-cycle is completed, thus allowing the landowner to produce a sustainable loop of forage production (Lewis et al. 1984; Hamilton 2008). Figure 2.2 shows a schematic of how a paddock system might look for a silvopasture that is established on a property with irregular borders (Hamilton 2008).

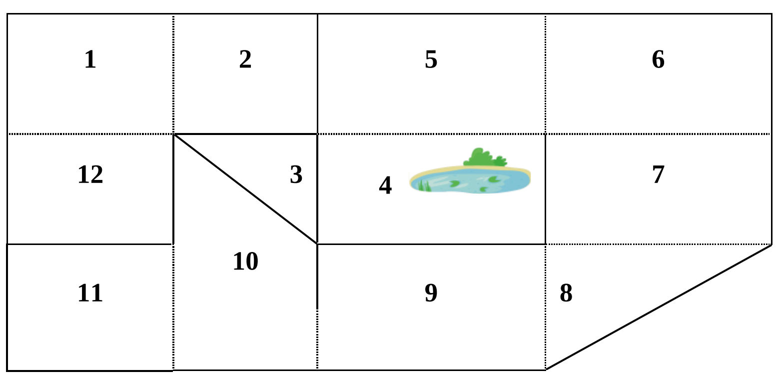

Figure 2.2. Example of a paddock system used for rotational livestock grazing in a silvopasture adapted from (Hamilton 2008)

2.3. Financial Benefits of Tree, Forage, and Livestock Interaction

Research suggests that silvopasture systems can incorporate southern yellow pine and livestock to produce an attractive land-use alternative relative to producing these components individually (Grado et al. 2001; Husak and Grado 2002). After trees have reached sufficient size and rotational grazing has commenced, research suggests overall profitability of a silvopasture may be increased because each component can improve the overall physical performance of the other components (Cutter et al. 1999; Garret et al. 2004; Hamilton 2008). For example, livestock grazing under timber can improve timber growth and reduce management costs by helping to control understory vegetation which can compete with trees for soil water and nutrients. In addition, livestock can recycle and return nutrients used by understory vegetation to the soil through their manure inputs (Lewis et al. 1984; Garret et al. 2004; Hamilton 2008).

Concurrently, trees can benefit livestock by providing shade which acts as a temperature buffer for the animals and their forage (Lewis et al. 1984; Garret et al. 2004; Hamilton 2008). By buffering animals and forage from heat and wind, livestock benefit via reduced heat stress and reduced water loss from their forage (Garret et al. 2004; Hamilton 2008). As a result, trees can reduce livestock production costs associated with water and supplemental feed (Garret et al. 2004; Hamilton 2008). It is important to remember however that livestock can damage young seedlings and it is recommended to postpone livestock for 3 to 4 years until seedlings reach 5 to 6 feet in height (Hamilton 2008). Because silvopastures are stocked at 200 - 400 trees per acre, there is increased importance on early tree survival when compared to traditional plantations due to this lower stocking level (Garret et al. 2004; Hamilton 2008; Brauer et al. 2009).

2.4. Financial and Economic Considerations for Silvopasture Establishment

There are both initial and long-term considerations for establishing a silvopasture which include personal objectives, markets, benefits and costs (Hamilton 2008; Godsey et. al. 2009). The primary purpose of a silvopasture is the production of a high-quality timber component to generate long-term revenue while producing livestock in the short-term. However personal objectives should guide what species are utilized for components and how intensively the system is managed. Based on those decisions, markets should be evaluated relative to the range of products the landowner has chosen to produce (Grewal and Levy 2008; Hamilton 2008). Analyzing a local market basically involves the evaluation of strengths, weaknesses, opportunities, and threats (competition/regulation/changing consumer demands), and then positioning the silvopasture operation to target the market segment that presents the greatest opportunity (Grewal and Levy 2008).

After identifying the opportunities and purpose, other short-term considerations must be given to establishment costs such as site preparation, seedlings, labor, and fencing while also considering long-term effects of things such as the most advantageous tax value classification of system, livestock and fence maintenance, watering structures for livestock, and labor/management costs (Godsey 2007; Hamilton 2008). Figure 2.3 shows a limited example of the table provided in Husak and Grado (2002) which shows the U.S. dollar costs and revenues associated with each silvopasture management activity in the year that it occurs.

Year	Activity	Cost ($/acre)	Revenue ($/acre)
0	Establishment	74.00	
1 to 30	Fence establishment/maint.	114.76	
2 to 30	Animal maintenance	5.00	
4 to 30	Steer/heifer sales		217.34
4 to 30	Hunting lease		6.89
15	Thinning		212.00
25	Thinning		565.15
30	Timber harvest		2,653.59

Figure 2.3. Shows the year, activity, costs and revenues associated with silvopasture management which should be identified and evaluated by those considering the establishment of a silvopasture system (Monetary Benefits of a Silvopasture System in the Southeastern United States adapted from Grado et al. 2001; Husak and Grado 2002).

Finally, a financial and economic analysis should be conducted to evaluate the relative profitability of the silvopasture and economically evaluated in comparison to any alternative land-use operations under consideration by the stakeholder (Husak and Grado 2002; Godsey 2007; Godsey et al. 2009). To be clear, financial concepts and metrics provide the basis for many of the analytic tools that economists use, thus conducting a financial analysis of each agroforestry component is generally needed so that economic analytics can evaluate and rank the attractiveness of financial alternatives (Graham and Dodd 1934; Varian 2006; Godsey 2007; Brooks 2008; Fleuriet 2008; Warren et al. 2008; Godsey et al. 2009; Ittelson 2009). Economics can and does incorporate the principles of finance and accounting in studying how individuals, businesses, and societies allocate finite resources among alternative productive uses for those resources (Graham and Dodd 1934; Graham and Spencer 1937; Graham 1949; Mansfield 1997; Godsey 2007; Plunkett et al. 2007; Brooks 2008; McConnel and Brue 2008; Godsey et al. 2009). Agroforestry operations allocate finite resources therefore basic financial and economic questions also apply to agroforestry production systems such as, what combination of goods can be produced and what ratio is more efficient (Graham and Dodd 1934; Nicholson 2002; Ekelund et al. 2006; Varian 2006; Godesey et al. 2009; Zhang and Pearse 2011)?

2.5. Silvopasture Economics: Components, Metrics, and Values

As previously mentioned silvopasture produces a combination of timber, forage, and livestock on the same land-unit, but please note, that the ratio (and profitability) of these three goods can differ among individual silvopastures due to site conditions or the species to be used as components (Godsey et al. 2009). However, the ratios of trees, forage, and cattle that can be produced are flexible but also finite; for example, there is an upper limit for tree and/or cattle stocking before forage production would be impossible. Thus financial and economic analyses can help identify and choose silvopasture component combinations and ratios by the identification of values and the trade-offs associated with the range of production choices. According to Godsey et al. (2009), the five most common economic tools used to evaluate agroforestry operations are net present value (NPV), annual equivalent value or equivalent annual income (AEV or EAI), benefit/cost ratio (BCR), internal rate of return (IRR), and land expectation value (LEV). Similarly, the three most commonly used metrics in financial analysis of traditional forestry projects are NPV, BCR, and IRR (Zhang and Pearse 2011).

Net present value (NPV) is commonly used to evaluate an investment's financial viability and is calculated by subtracting the present value of total costs from the present value of total revenues (Varian 2006; Godsey et al. 2009; Zhang and Pearse 2011). Benefit/cost ratio (BCR) is calculated by present value of total revenues by the present value of total costs and is used to indicate the ratio of dollar benefit generated per each dollar cost. The internal rate of return

(IRR) is a discount rate at which the NPV of an investment equals zero (Godesey et al. 2009). Land expectation value (LEV) is used to estimate land value based on the NPV of all expected future revenues generated by a particular land-use (Husak and Grado 2002; Godsey et al. 2009; Zhang and Pearse 2011). The LEV metric, also known as the Faustmann-formula, has been used in traditional forest management primarily to calculate land value based on its ability to continuously produce timber (Godsey et al. 2009; Zhang and Pearse 2011). However, the LEV metric can be used with both tree and agricultural production (Godsey et al. 2009).

Individual financial metrics and economic methods have advantages under various circumstances, thus the circumstances of each potential investment should be thoroughly considered and assumptions should be defined (Graham 1952; Godsey et al. 2009; Zhang and Pearse 2011). For example, Husak and Grado (2002) is well-known economic analysis of the monetary and wildlife benefits produced by the incorporation of forestry and agricultural data into a hypothetical silvopasture in the southeastern U.S. to demonstrate that the adoption of silvopasture is both economically and biologically feasible. Using LEV, AEV, and ROR, not only did Husak and Grado (2002) determine that a silvopasture utilizing loblolly pine and cattle (cow-calve operation) was feasible but was more financially attractive when compared and contrasted to the individual production of soybeans, rice, cattle, and pine plantation. Finally, their analysis suggested that in addition to having more attractive cash-flows, silvopastures incorporating hunting leases could, on average, yield 3.1% - 30.6% more value per acre over silvopastures which did not incorporate them (Husak and Grado 2002).

According to Godsey et al. (2009), the five economic tools most commonly used in agroforestry are net present value (NPV), annual equivalent value or equivalent annual income (AEV or EAI), benefit/cost ratio (BCR), internal rate of return (IRR), and land expectation value

(LEV). Because agroforestry is the combination of two or more farm enterprises, these metrics are designed and used with the purpose of evaluating the individual and collective values associated with the operation's revenues, assets, fixed costs, variable cash and non-cash costs, and owner's equity that are associated with each enterprise such as timber and livestock production, land values, annual fence maintenance, equipment, inflation and taxes, but each metric has an appropriate use in evaluating and ranking multiple projects in order of their financial attractiveness (Warrant et al. 2008; Zhang and Pearse 2011).

It is possible however for a timberland or silvopasture owner to experience situations in which those metrics are inaccurate or incapable of incorporating certain values. Economic modeling of free cash-flow (FCF), discounted free cash (DCF), and net present value (NPV) are important tools that can be used by economists in many situations where liquidity, earning power, and business assets need to be valued in order to evaluate trade-offs among alternative options (Varian 2006; Brooks 2008; Ittleson 2009; Zhang and Pearse 2011). However, NPV along with LEV, EAI/AEV, and ROR (which are derived from the NPV calculation) can be intrinsically limited by certain situations depending on many factors including the level of accuracy needed, available data, capabilities of the model, and the variance among individual objectives, circumstances, and regions (Brooks 2008; Houdet et al. 2009; Zhang and Pearse 2011). There is a gap in the agroforestry literature regarding the valuation of pre-merchantable pine stands in silvopasture systems, and this gap could conceivably lead to the overvaluation or undervaluation of the tree component if the farmer or landowner finds it undesirable or impractical to collect such extensive data and conduct such robust economic modeling (Ward et al. 2004; Brooks 2008; Houdet et al. 2009; Zhang and Pearse 2011).

In the case of valuing the pre-merchantable timber alone without the land value, and when determining future timber market demands, prices and cash flows has been deemed implausible or undesirable, forest economists have used the replacement cost approach (Zhang and Pearse 2011). The replacement cost approach (or just cost approach) involves using the nominal price or cost of tree establishment to determine and substitute (its time value) for the cost of replacing the pre-merchantable timber held for investment or that is considered an asset where value appreciates along with biological growth (Zhang and Pearse 2011). This calculation is carried out by compounding the per acre cost of establishing a stand (which might include seedlings, labor, herbicide treatment etc.) forward for the amount of time (number of years) since establishment, at a specified interest rate, to its present value (Zhang and Pearse 2011).

Although the replacement cost value would not be able to replace a 3-year old loblolly stand in a day (or even two years), the replacement cost value is used to represent the rise in monetary cost of replanting the stand due to annual inflations but also the opportunity cost of what the cash expense for tree establishment could have earned had it been put to work elsewhere, such as in a savings account, certificate of deposit, government or corporate bond, or stock equity (Zhang and Pearse 2011). The replacement cost of pre-merchantable timber is calculated in the same manner as would be the compound interest on a savings account at a commercial bank (Zhang and Pearse 2011). The replacement cost calculation follows the form $V_n = V_0 (1+i)^n$ where V_n is the present value of the investment, V_0 is the establishment cost in the year of establishment, (1+i) is the interest rate, and n = number of years or periods since establishment. For example, a landowner wants to know the present value of replacing a 3-year old southern pine timber tract that is on a 25 year rotation. The establishment cost was $100.00/acre to establish, and the desired interest rate (expected rate of return) is 5%. The replacement cost would be calculated as follows: 1) $V_n = 100 (1 + .05)^3$; 2) $V_n = 100 (1.1576)$; 3) $V_n = \$115.76$/acre.

Because the purpose of most landowners, who establish timber as an investment, is to realize income from the future sales of timber, the present value (replacement cost) of the pre-merchantable timber is understood to represent the future value of cash income generated by future timber sales, but according to Zhang and Pearse (2011) the replacement cost approach has an intrinsic link with NPV and future cash flows. However, at minimum, the replacement cost will reflect and represent the opportunity cost associated with what the cash, that is invested in timber establishment, could have earned if it had been put to the next best alternative such as $100.00 cash in a savings account, bonds, or common stocks earning the same interest rate (Godsey et al. 2009; Zhang and Pearse 2011). Timberland investments have been a historically attractive way to diversify an investment portfolio and as a method for hedging the value of cash against inflation (Zhang and Pearse 2011). According to the National Council of Real Estate Investment Fiduciary (U.S. Trust 2010), from 1991 to 2009 southeastern timberlands provided investors with a higher average annual return (10.3% total; approximately 5.5% for timber and 4.8% for the underlying land) and lower volatility or price risk (6.6%) than did assets of the 500 organizations listed in the S&P 500.

The replacement cost approach can therefore be used as a method for assigning a contingent value estimate to pre-merchantable that is expect to produce timber as it matures over the rotation period (Zhang and Pearse 2011). Moreover, the value of pre-merchantable timber can be valued more accurately by the replacement cost approach than by discounted cash flows (DCF/NPV) the younger the pre-merchantable stand is therefore the replacement cost approach is most commonly used for accounting and tax purposes until the trees reach a marketable size

(Zhang and Pearse 2011). Figure 2.4 shows an example of compound interest through which is used to describe the basis for the replacement cost approach of valuing pre-merchantable timber by forest economists.

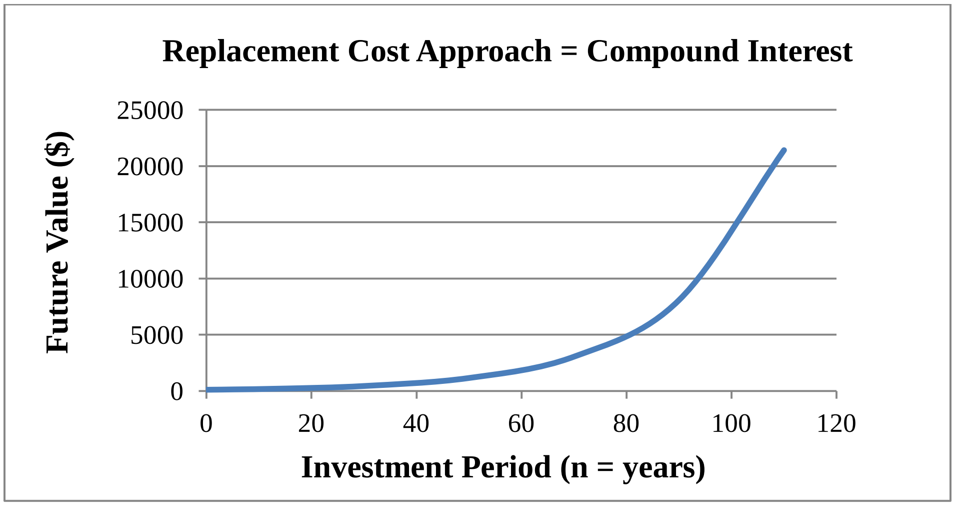

Figure 2.4. Time value of money: Initial investment of $100.00 that earns a 5% interest that is compounded annually.

The applicability of the replacement cost approach may be better understood by considering the old and popular adage which says "trees don't read the Wall Street Journal" (Opdyke 2010). Just because Wall Street doesn't have a price quotation for an asset doesn't mean that the asset valueless (Graham and Dodd 1934; Graham 1949; Opdyke 2010). The value of pre-merchantable timber, as an investment or capital asset, appreciates in value through time because of biological growth (U.S. Trust 2010; Zhang and Pearse 2011).

Because of biological growth, pre-merchantable loblolly will, on average, annually increase in mass and thus eventually become marketable timber sold by the ton, cord or another metric such as per thousand board feet (MBF), and because biological growth will increase the price basis, metric or unit by which timber is sold at market, biological growth, in general, equals greater mass/length/density that, when multiplied by price, can be sold at a higher market value relatively speaking (U.S. Trust 2010; Zhang and Pearse 2011). The rate of biological growth is thus very similar to compound interest rates, and the replacement cost approach is based on the general trend that the rate of biological growth of southern pines steadily increases and eventually a marketable value (Zhang and Pearse 2011).

However, as noted by Zhang and Pearse (2011), the stand establishment cost is intrinsically linked through biological growth to future timber values. Because of this link, the replacement cost approach is not completely separate from the methods of discounting future revenues such as NPV or IRR however each method will produce a different value for the same timber stand, thus the stands age will, in part, determine what method of valuation is appropriate. Because the term value is relative, the interest rates and methods for assigning value should be relative to the site specifics, circumstance, and objectives of the landowner/investor (Godesy et al. 2009; Zhang and Pearse 2011). Thus, if a major objective involves high-quality timber component, some landowners may want to understand how and why the replacement cost approach (compounding the establishment cost) and NPV (discounting future timber revenue) are intrinsically linked, and how to value pre-merchantable using both valuation methods and how they are reconciled. According to Zhang and Pearse (2011), the link between stand establishment cost and discounted future timber revenue can be shown by calculation of the internal rate of return (IRR).

In order to do so, an example of the basic discounting process used for NPV calculations of future timber revenue is required (Zhang and Pearse 2011). Basic discounting requires an estimate of the revenue at final harvest, the number of years in the rotation, the current age of the timber stand, and the discount rate (rate of return) desired or expected by the stakeholder. The revenue produced at final harvest is then discounted, at the specified rate, for the time difference (years) between final harvest and the current age of the stand. After data are obtained, discounting calculations follow the general form $V_0 = V_n/(1 + i)^n$ where V_0 = the present value of the timber revenue in the current year, V_n = the expected future value of the timber revenue in year n, $(1 + i)$ = the discount rate, n = the number of years in the rotation to be discounted. The result of the calculation will be the present value (V_0) of the timber's expected future value.

For example, using the numbers provided in the example calculating the replacement cost approach, a 3 year-old southern pine timber tract has an expected rotation length of 25 years, when it will yield 50 tons/acre of saw-timber and earn a 5% rate of return on the investment. According to timber price listing service, the average pine saw-timber price was \$24.00/ton in the 1st quarter of 2012, therefore by multiplying 50 tons/acre by \$24.00/ton, it is expected that the timber will produce \$1,200.00/acre. Following the general equation $V_0 = V_n/(1 + i)^n$ the discounting process for this example is as follows: 1) $V_0 = \$1200/(1.05)^{22}$; 2) $V_0 = \$1200/2.925$; 3) $V_0 = \$410.22$.

As can be seen from comparing this example to that of the replacement cost approach, although the same timber stand data was used in the replacement cost approach and discounted future timber revenue, two different values (\$116/acre and \$410/acre) were given for the same stand, same age of 3-years, using the same interest/discount rate of 5%. To reconcile the difference between values, the internal rate of return (IRR) is calculated using data from each method. For IRR calculations, the required data are the stand establishment cost, revenue at final harvest, and the total rotation years. Calculation of the IRR follows the form $(IRR) = [(V_n/V_0)^{-1/25}] - 1$ where V_n = the expected future value of timber revenue and V_0 = the establishment cost.

Using the \$1,200.00/acre revenue at final harvest, \$100/acre stand establishment cost, and the 25 year rotation is calculated as follows: 1) IRR = $[(\$1200/\$100)^{-1/25}]$; 2) IRR = 1.1045 – 1; 3) IRR = 10.45%.

The IRR of 10.45% represents both the interest rate at which \$100.00 is compounded to reach a value of \$1,200.00 in 25 years $\{1{,}200 = 100 \times (1 + 0.1045)^{25}\}$, and it is also the discount rate that used to determine what \$1,200.00 to be received 25 years in the future would be worth today $\{\$100 = \$1200/(1.1045)^{25}\}$. This process is the reconciliation of the income approach and replacement cost approach. The IRR (%) can then be substituted in either compounding or discounting procedures as the interest or discount rate and will produce the same result at any stand age (Zhang and Pearse 2011).

However, the problem with IRR is that it partially relies upon the timber quantity and value at harvest, similar to most timber value calculations using NPV, LEV, and AEV. Although historical southern pine timber has averaged 5.5% return on investment there is no guarantee that it will do so in the future because biological growth, mortality rates, demands, markets, and prices can change (U.S. Trust 2010; Zhang and Pearse 2011). In that case, the replacement cost approach can use an interest rate of 3% because it is accepted to represent the average annual rate of inflation although inflation rates fluctuate (Zhang and Pearse 2011). A 3% interest rate is generally accepted because long-term financial investments, such as timberland and silvopasture, are typically deemed unattractive if they do not generate at least a 3% rate of return which on average will protect the investor’s monetary value from being eroded by inflation (Graham 1949; Godsey et al. 2009; U.S. Trust 2010; Zhang and Pearse 2011).

In cases that involve valuing the young pine stands, the financial metrics used by standard economic methods for valuing that timber may not be most appropriate. This is because those economic metrics are all based and reliant on financial metrics for all future timber volumes, market prices, and cash-flows. Although the production of high-quality timber is part of a silvopasture's purpose, economic methods which value pre-merchantable timber based on forecasting and discounting all of the timber revenue expected many years in the future can lead to overvaluation of the asset (Zhang and Pearse 2011). In contrast, the replacement cost approach can undervalue timber, but it is a financial metric that is intrinsically linked to future timber revenue and can also be used to represent the opportunity costs of alternate investing activities both in the present and near future and thus provides a more accurate estimate the younger the timber stand is (Zhang and Pearse 2011).

Furthermore, the tree component is also intended to improve cattle profit margins and potentially generate financial benefits from tax incentives, cost-share programs, and hunting leases. Therefore, use of the replacement cost approach and a minimum interest rate of 3% (conservative interest rate) provides a reasonable financial metric for the value of pre-merchantable timber. Moreover, the relative financial value produced by compounding the stand establishment cost can be calculated quickly when the establishment cost is known. Combined with the discounted revenues the landowner expects over two or three years of cattle or hay production, the timber, cattle and hay values can be plugged into economic metrics such as NPV, and may more accurately reflect silvopasture component values and potential trade-offs which may be necessary in some short-term management situations. In any case, value is a relative term and in many cases it is not synonymous as price therefore the methods, interest rates and resulting valuation should be relative to the investor's situation and objectives (Graham and Dodd 1934; Varian 2006; Godsey et al. 2009; Zhang and Pearse 2011).

The analytical tools of finance and economics can provide valuable insights to biological sciences as well pertinent information regarding the performance of silvopasture components as a collective unit or in comparisons to operations which may produce timber, forage, or livestock individually (Graham 1952; Godsey et al. 2009; Zhang and Pearse 2011). However, the additional benefits that stem from the ability of a silvopasture to enhance environmental services should not be ignored (Grado et al. 2001; Alavalapati and Mercer 2005). In addition to the well known Husak and Grado (2002) analysis of silvopasture, other research suggests that additional financial benefits from wildlife and the broader environment based ecological attributes of silvopasture including the ability to improve wildlife habitat, reduce soil erosion, and improve water quality (Godsey 2007; Hamilton 2008; Godsey et al. 2009; Sharrow et al. 2009). As the trees in a silvopasture mature, they alter the structural, vertical and horizontal composition of other habitat components that can lead to increased biodiversity, which in turn can be translated into additional financial benefits from annual tax incentives, payments from cost-share programs such as the Conservation Reserve Program (CRP) and Wildlife Habitat Incentive Program (WHIP), and annual hunting leases (Husak and Grado 2002; Rollins et al. 2004; Godsey 2007; Bambo et al. 2009).

In most cases, the practice of silvopasture improves wildlife habitat and attracts species such as wild-turkey (*Meliagris gallapavo*), white-tailed deer (*Odocoileus virginianus*), and rabbits (*Sylvilagus spp.*) by increasing the availability, diversity and quality of seasonal resources (Leopold 1933; Grado et al. 2001; Sharrow 2001; Robinson 2005; Nowak et al. 2008; Sharrow et al. 2009). However, the ability of a pine silvopasture system to alter the structure of habitat components and attract wildlife also creates the potential for wildlife related damages (Schuhmann and Schwabe 2000; Conover 2002; Rollins et al. 2004). The ability of a silvopasture to attract wildlife creates the potential for damages to the timber component of a young silvopasture that in turn could affect the timing of livestock introduction, which ultimately could reduce a silvopastures financial performance and future management.

2.6. Wildlife Browse Damage: A Potential Cost to Pine Silvopasture Establishment

Regarding traditional forestry and agricultural practices, deer are known to cause severe damage to orchards, nurseries, ornamental trees, and shrubs (Waller and Alverson 1997; Yates et al. 1997; Conover 2002; Barras et. al. 2005; Semans and Helon 2008). In the United States for example, wildlife professionals estimate that the annual cost of deer damage to timber and agricultural productivity is approximately $750 and $500 million dollars respectively (Waller and Alverson 1997; Conover 2002; Seamans and Helon 2008). Likewise, rabbits may be able to impact the financial performance of a silvopasture, but unlike deer, there is limited quantitative data pertaining to the economic impact of rabbit damage (Shelton and Cain 2002).

No silvopasture research has studied the effect of deer and rabbit browse damage on the southern yellow pine silvopastures. Even traditional forestry research reports little data on this subject, but with regards to deer, professionals at the USDA Forest Service state that if excess deer are not harvested through hunting, they will soon deplete preferred food items and can turn to browsing young pine trees (Campbell 1976; Yates et al. 1997). With regards to preferred food items, deer utilize a variety of plant species throughout the year depending on the energetic and nutritional requirements of deer’s life-cycle events including body growth and maintenance, antler development, gestation (pregnancy) and lactation (Miller and Marchinton 1995; Dickson 2001).

In Alabama, it is common for deer to browse herbaceous plants such as wild grape/muscadine (*Vitis rotundifolia*), Japanese honeysuckle (*Lonicera japonica*), common persimmon (*Dyospyros virginiana*), blackberry/dewberry (*Rubus spp.*), green-briar (*Smilax spp.*), sparkleberry/blueberry (*Vaccinium spp.*), and American beautyberry (*Phytolacca americana*) (Dickson 2001; Cook and Gray 2003). These items are "preferred" by deer because they have high nutritional quality and are easy for deer to digest (Dickson 2001; Cook and Gray 2003). If these preferred species are limited, deer can turn to browsing young southern pines. As a result, deer can inflict severe damage to young pines that limit or eliminate height growth for the first five to six years (Campbell 1976; Waller and Alverson 1997; Yates et al. 1997; Brockway and Lewis 2003).

Rabbits may be able to impact the timber component of a silvopasture, but like with deer, there is limited quantitative data pertaining to the extent and effects of rabbit damage to southern pine (Shelton and Cain 2002). Rabbits, unlike deer, are short-lived herbivores, with populations experiencing an annual mortality rate of 80% to 90% (Dickson 2001). On an annual basis, rabbit populations fluctuate widely due both to climate effects on food items like grasses and forbs, and also because rabbits are prey for a wide range of animals (Dickson 2001). Although data is limited, a few studies involving traditional loblolly pine-plantations have observed that rabbit browse damage can reduce the annual growth of loblolly seedlings.

Visually identifying and differentiating between deer and rabbit browse damage is determined by examining the edges of each seedling's terminal buds and lateral stems (Conover 2002; Barras et al. 2005). Deer lack upper incisors, meaning that they must tear vegetation or woody browse, such as green-briar or an oak sapling (*Quercus spp.*), resulting in a rough or jagged appearance and is most often accompanied by plant fibers hanging from the perimeter of a damaged stem (Miller and Marchinton 1995; Conover 2002). Conversely, a plant that has been browsed by a rabbit will have an appearance of a smooth cut as opposed to the rough or jagged appearance of deer browse because rabbits have both upper and lower incisors (Conover 2002).

Even though data is limited for both deer and rabbits, a few studies have examined rabbit browse damage to species of southern yellow pine. In Texas, Hunt (1968) conducted an experiment from 1959 to 1963 in which 3-plots, containing 1,400 loblolly seedlings each. All 4,200 seedlings were examined for damage and heights measured. Approximately 5% of seedlings in each plot had terminal bud damage from rabbit browse. The heights were initially measured in January of 1959 with subsequent height measurements occurring in 1961, 1962, and 1963. After four growing seasons, undamaged seedlings averaged 7.65 feet in height and damaged seedlings averaged 6.32 feet in height. The author reported that statistical analyses determined that the damaged loblolly seedlings were significantly shorter than those that were undamaged (Hunt 1968).

In Louisiana, Wakeley (1970) conducted a similar analysis using data from a similar experiment in which the terminal buds of 4,896 slash pine, 3,475 loblolly seedlings and 1,745 shortleaf seedlings were initially recorded to have been damaged by rabbits shortly after being planted in the winters of 1924 to 1925 and 1925 to 1926. The author was interested in examining the effect of tree arrangement, density on the final volume of timber produced. The initial and individual condition of all seedlings, damaged and undamaged, were recorded. Subsequently, all trees were individually re-examined and heights recorded at age 5, 10, and 30. Wakeley (1970) analyzed these data and found that the average height of damaged seedlings was within 17% of the undamaged seedlings by year 5. Additionally, please note that Wakeley

(1970), unlike Hunt (1968), did not record seedling heights until year-5 and does not state what the heights were or whether or not that 17% difference was significant.

More recently in Arkansas, Shelton and Cain (2002) conducted a controlled study to investigate recovery of 1-year old loblolly pine seedlings from simulated rabbit browse damage. The authors were interested examining the effect that the extent and seasonality of browse damage have on the rate of recovery of naturally regenerating loblolly pine, probability of multiple stems, and probability of damage from tip moth (*Rhyacionia frustrana*). The study was conducted on forest lands owned by the University of Arkansas at Monticello. Loblolly seedlings were extracted from an area beneath mature loblolly trees and re-planted at the study site in prepared seedbeds.

Shelton and Cain (2002) randomly assigned seedlings to one of five damage treatments and two season treatments being winter and spring. The five damage treatments were defined at the point of clipping: one-half the distance between the root collar and cotyledons and to retain 25, 50, 75, and 100% of the height from the cotyledons to the terminal bud's winter position. For winter, the 100% treatment represented an unclipped control. Non-linear regression was used to predict the second year height, probability of multiple stems, and probability of tip moth damage. Their study observed 100% mortality for seedlings that were clipped below the cotyledon but an average of 0.3% mortality in the other four treatments where seedlings were clipped above cotyledons or were not clipped at all. Their results showed the height of severely damaged seedlings (25% of height remaining) to have 2nd year heights reduced by 40% in comparison to the remaining treatments (Shelton and Cain 2002).

The results of those studies were far from conclusive but they do agree rabbit browse damage can have an adverse impact on mean seedling height in the first 4 to 5 years from planting (Hunt 1968; Wakeley 1970; Shelton and Cain 2002). Although a silvopasture manager may supplement the livestock revenue while trees mature by harvesting hay or row crops from the wide alleyways, the potential impact of deer and rabbit browse damage on the growth of southern yellow pine during the first 3 to 4 years may prove important to landowners and the financial performance of a silvopasture system.

For years, many considered cattle grazing and forestry to be mutually exclusive, however, a little more than 30 years ago the science of silvopasture began to suggest that livestock need be excluded only for the first few years, and then each will benefit the other by working together (Clason 1995; Cutter et al. 1999). Silvopastures are commonly stocked at 200 to 400 stems per acre which may be less than half the tree stocking in a pine plantation (500 to 800 trees/acre or more), but economic studies suggest that the trees in a silvopasture mature they can produce a diversity of financial benefits before being sold as merchantable timber including improved livestock performance at lower costs due to the benefit of tree shade in reducing heat stress and animal maintenance costs, and the annual revenue from hunting leases (Garret et al. 2004; Hamilton 2008; Godsey et al. 2009). However, the lower stocking and delay of livestock make it desirable for the greatest number of trees to establish and grow.

As previously stated, many factors can have an effect on southern pine growth and mortality, whether or not the trees are part of a plantation, silvopasture, or naturally regenerated stand (Bendfeldt et al. 2001; Brauer et al. 2009; Sharrow et al. 2009). Although foresters have studied the effects which factors such as soil chemistry, nutrient competition, diseases like fusiform rust, and pests such as southern pine beetle (*Dendroctonus frontalis)* can have on pine growth and mortality, data are limited regarding their effect on southern pine in a silvopasture system stocked at 200 to 400 trees per acre (Shelton and Cain 2002). The assumption follows then that because previous research has found silvopasture systems to be a viable method for producing high-quality timber, the overall effects many natural factors have the growth and mortality of southern yellow pine must have been within acceptable limits relative to the 200 to 400 trees per acre. Were it not so, economic research and analyses could not have concluded that silvopasture is financially viable method for producing high-quality southern yellow pine timber.

Furthermore, for southern yellow pines in a silvopasture system, the livestock component has become a potentially limiting factor in addition to those already known. Similarly, the effect of damages and mortality to young pines in a silvopasture caused by livestock is not well understood, but because of the same economic research, it is implied that the damage levels must have been manageable as with the natural limiting factors. However, the results of previous research on pine silvopastures also implies that the combination damages due to natural and livestock factors can be both biologically and economically destructive thus scientists and professional managers in Hamilton (2008) recommend the exclusion of livestock during the first 3 to 4 years.

2.7. Economics of Wildlife Damage: A Gap in Agroforestry Literature

The literature provides few examples for incorporating wildlife damage in standard timber valuation methods and less on valuing damage to the timber component of agroforestry systems. In Ward et al. (2004), the authors state that although limited published data existed with regards to quantifying the economics of deer damage in forestry, most of the prior research suggested that the benefits and effectiveness of using tree guards, shelters, or fencing to protect seedlings in anticipation of deer damage were arguable and may not be cost effective. The authors were concerned with the restricted nature of economic models concerning their potential undervaluation of the impacts which mammals can have on forestry in Europe and North America (Ward et al. 2004).

In order to improve forest economic models, their purpose was to quantify the financial costs and benefits of roe deer (*Capreolus capreolus*) browsing damage on seedlings in British forestry, stating that excessive densities of ungulates including white-tailed deer have been shown to negatively impact plant diversity as well as the economics of agriculture and forestry (Ward et al. 2004). The authors assessed the cost of roe deer damage to Sitka spruce (*Picea sitchensis*) by analyzing the net present value (NPV) per hectare within a cost-benefit framework by modeling different tree damage scenarios that translated into lower financial performance of the forestry practice due to lower timber yield/hectare (Ward et al. 2004). The results of the study concluded that the primary financial impact of roe deer damage was caused not by lower timber yield or wood quality but rather by increased management costs of an extended tree establishment phase due to browse damage on the terminal buds (leaders) of spruce seedlings (Ward et al. 2004).

However, examples from traditional agricultural and forestry practices most often use net present value of future cash-flows for timber, and acknowledge the need for more short-term financial data because of the difficulty that comes with accurately identifying costs, future timber prices, discount rates, and NPV estimates when both short- and long-term data are lacking. For example, similar to Ward et al. (2004), Godsey and Dwyer (2008) model the NPV of deer damage in a black walnut (*Juglans nigra*) plantation in Missouri, U.S.A. The plantation was surveyed for signs of mechanical damage caused by deer rubbing young trees, 5 to 10 years old, with their antlers thereby causing damage to the trees cambium. Subjective judgments were used to estimate four categories of damage impacts and potential value loss of veneer quality logs

(Godsey and Dwyer 2008). Future timber yields and prices were estimated for stands with and without damage. Those future values were then discounted back to present values and summed to arrive at the net present (NPV) of systems with and without damage across 6 successive discount rates in order to present range of relative values. The value loss or difference between NPV no damage and NPV with damage, were taken to represent the landowners willingness-to-pay (WTP) for protection of young trees. Willingness-to-Pay in this case is reflected on by shift of the supply curve towards the origin thereby changing amount of consumer surplus (Ekelund et al. 2006; Godsey and Dwyer 2008). Due to the deer damage, the lowered supply of black walnut timber comes at a higher production price. This higher price results with less market consumers who are willing or able to pay the increased price thus the landowner must reduce price; therefore the cost of deer damage becomes a sunk cost which the producer cannot recover (Godsey and Dwyer 2008). Similar to Ward et al. (2004), the study concludes by highlighting the sensitivity of accurately valuing the costs of wildlife damage based on uncertain future wood volumes, quality, market prices, and discount rates and state that future research is needed on the potential impact of deer damage to timber values.

Limited research exists regarding the proper financial data collection and economic models for wildlife damages in traditional forestry systems and it appears that a similar limitation exists regarding the timber component of a silvopasture system. However, if humans are to continue benefiting from agroforestry, the costs of wildlife damage must be understood so that they can be better managed (Schuhmann and Schwabe 2000; Conover 2002; Ward et al. 2004). The field of wildlife damage management is defined as increasing the positive values of wildlife by decreasing the negative values, which is strikingly similar to the pure economic principle of profit maximization by cost minimization (Conover 2002; Varian 2006). The field of wildlife damage management itself is now evolving more from management towards what's considered a true science (Conover 2002). The concept of wildlife damage is necessarily relative to humans, for without humans, human-wildlife conflict does not exist (Conover 2002).

Wildlife damage management is an interdisciplinary science of relativity which requires the application of many disciplines (Conover 2002). Human population growth is projected to continue increasing at an exponential rate well into the 21st century, doubling the 2010 levels of food, fiber and energy consumption by 2050 (Nowak et al. 2005; Udawatta and Godsey 2010; Prinn and Reilly 2012). According to research, humans will be required to adopt and adapt multi-functional land-use systems on a scale that has never before been seen (USDA 2011). The rise of agroforestry systems has occurred in little more than 30 years, and if it does continue, the implementation of agroforestry systems will indeed alter landscapes; thus the science of wildlife damage relativity suggests human-wildlife conflict cannot be escaped (Conover 2002; Udawatta and Godsey 2010). The efficiency of a silvopasture system may therefore be questioned under sustained damages from local wildlife populations, a subject that increasingly must be understood (Hunt 1968; Campbell 1976; Pearson 1984; Miller and Marchinton 1995; Waller and Alverson 1997; Conover 2002; Husak and Grado 2002; Shelton and Cain 2002; Shwiff 2004; Godsey and Dwyer 2008; Hamilton 2008; Sharrow et al. 2009; USDA National Agroforestry Center 2010; World Agroforestry Center 2010; Zhang and Pearse 2011).

CHAPTER 3

SILVOPASTURE ESTABLISHMENT AND ECONOMICS: THE COST OF WILDLIFE BROWSE DAMAGE AT REDSTONE ARSENAL

3.1. INTRODUCTION

According to the MIT Center for Energy and Environmental Policy Research, by the year 2050 global demand for food and energy will be approximately double the amounts consumed in 2010 (Reilly and Paltsev 2007; Prinn and Reilly 2012). The estimates produced by MIT suggest that the increased demand for food and energy dictates that organizations, producers and consumers will have to adapt and utilize multi-functional agricultural and forest systems as never before (Udawatta and Godsey 2010; Prinn and Reilly 2012; Susaeta et al. 2012). Conversely, many believe that the multi-functional agroforestry practices of alley-cropping, forest-farming, riparian buffers, silvopasture, and wind-breaks have the potential to significantly increase farm and forest land-use efficiency (Clason 1995; Husak and Grado 2002; Workman 2003). In contrast to many traditional management techniques, agroforestry practices improve efficiency by systematically producing multiple goods and services on the same land-unit (Husak and Grado 2002; Hamilton 2008; World Agroforestry Center 2010).

The use of agroforestry techniques has increased in the last 30 years, with silvopasture becoming the most common practice in the southeastern United States (Sharrow 2001; Husak and Grado 2002; Sharrow and Fletcher 2003; Hamilton 2008). Many public and private organizations are investigating the potential costs and benefits of expanding its use across the

U.S. South (Sorrow 2011; Susaeta et al. 2012). For example, as a result of economic pressure and its commitment to sustainable ecosystem management, in December of 2009 the United States Army at Redstone Arsenal (RSA) implemented a limited area of loblolly pine silvopasture to assess the feasibility of expanding its use on up to 1,500 acres of open pasture. Silvopastures are designed to systematically integrate timber, forage, and livestock production on the same land-unit (Stainback and Alavalapati 2004; Hamilton 2008; Hill 2008; Oswald et al. 2008; Sharrow et al. 2009). Silvopasture is used to produce high-value timber products, such as saw-timber and veneer-logs, while generating short-term cash-flows from the sale of livestock and other products such as hay and pine-straw (Long 2003; Hamilton 2008).

In the southeastern U.S., yellow-pines such as loblolly (*Pinus taeda*), and slash (*Pinus elliottii*), and longleaf (*Pinus palustris*) may be used as the timber component of a silvopasture system (Kush et al. 2004; Hamilton 2008). Pine silvopastures can be established on existing pasture land by planting single, double, or triple rows of trees while leaving wide, unplanted corridors between them (Lewis et al. 1984; Clason 1995; Hamilton 2008; Sharrow et al. 2009). The forage component of a silvopasture can include various mixtures of warm- and/or cool-season legumes and grasses to be used as hay or food for livestock (Hamilton 2008). The establishment and production of forage in silvopasture is similar to that of traditional pasture management but is different in that the selected forage species should be more shade tolerant. Suitable legumes include various species of clover (*Trifolium spp.*) and vetch (*Vicia spp.*) while grasses may include rye-grass (*Lolium spp.*) or native species such as little bluestem (*Schizachyrium scoparium*) and eastern gammagrass (*Tripsacum dactaloides*) (Hamilton 2008).

Likewise, the livestock component may be selected from a range of grazing animals including domestic cattle (*Bos taurus*), domestic goats (*Capra hircus*), or domestic sheep (*Ovis *aries*) (Garret et al. 2004; Hamilton 2008). Proper timing of livestock introduction is important as livestock can damage young seedlings by browsing, trampling, and rubbing them during the first 3 to 4 years from establishment (Hamilton 2008; Brauer et al. 2009). Accordingly, the United States Department of Agriculture's National Agroforestry Center (USDA-NAC) recommends that when landowners establish a pine silvopasture on non-forested tracts, livestock grazing should be delayed for approximately 3 to 4 years (Hamilton 2008). During this time, many southern yellow pine trees reach 5 to 6 feet in height and thus avoid being damaged by livestock (Hamilton 2008).

Through time, trees can benefit livestock mainly by providing shade which acts as a temperature buffer for the animals and their forage (Garret et al. 2004). By buffering animals and forage from heat, livestock benefit via reduced heat induced physiological stress and forage by reduced water and nutrient loss (Lewis et al. 1984; Garret et al. 2004; Hamilton 2008). As a result, trees can reduce livestock production costs associated with water and supplemental feed (Lewis et al. 1984; Hamilton 2008).

However, the postponement of livestock for 3 to 4 years can be prohibitive and is an important consideration for those establishing a silvopasture with one of the main reasons being that participating farmers and landowners must forgo the income and cash flow from livestock sales, both of which are important for small businesses and thereby will be for a recently undertaken agroforestry enterprise (Godsey 2007; Godsey et al. 2009). Accordingly, studies have addressed these concerns and suggest that landowners may supplement the livestock revenue during the first 3 to 4 years by harvesting hay or row-crops from the wide alleyways between the tree rows (Husak and Grado 2002; Hamilton 2008).

Protection of the timber component during the early years is imperative, not only for the future financial benefit of timber income and enhance livestock performance but because as the trees mature they can produce benefits by enhancing wildlife habitat as well as the broader environment (Husak and Grado 2002; Fike et al. 2004; Rollins et al. 2004; Lemus 2009). These studies suggest that as the trees in a silvopasture mature they produce additional financial benefits from annual tax incentives, payments from cost-share programs such as the Conservation Reserve Program (CRP) and Wildlife Habitat Incentive Program (WHIP), and hunting leases (Husak and Grado 2002; Godsey 2007).

In most cases, the practice of silvopasture improves wildlife habitat and attracts species such as wild-turkey (*Meliagris gallapavo*), white-tailed deer (*Odocoileus virginianus*), and rabbits (*Sylvilagus spp.*), benefitting both the landowner and nature (Hodge et al. 1999; Grado et al. 2001; Robinson 2005; Nowak et al. 2008; Sharrow et al. 2009). However, the ability of a pine silvopasture system to attract wildlife also creates the potential for wildlife related damages to the timber component in a young silvopasture that in turn could affect the timing of livestock introduction. The result of such a scenario could clearly reduce the financial performance of a silvopasture, but this potential is not well understood.

As for the example of Redstone Arsenal, after an assessment of the 1-year old loblolly pine seedlings in December of 2010, RSA personnel reported the existence of wildlife browse damage on young seedlings. The presence of damage generated concern among RSA managers about the impact to timber growth and value with respect to livestock because they intended to incorporate cattle grazing leases (similar to those which they currently use on open pastureland) after the seedlings reached sufficient size. Due to the need for cattle grazing revenue, they were interested in understanding the potential impact that wildlife and cattle damage may have on the value of loblolly pine. This made Redstone Arsenal an ideal location for research to examine the impact of wildlife browse damage on the growth and value of tree and livestock components in a pine based silvopasture system in Alabama. Valuing and accounting for the monetary benefits of animal damage is not straightforward when damage is caused to a single agricultural crop, hence it should not prove to be less difficult when estimating value for wildlife damage to the multiple-use systems such as silvopasture. In many cases however stakeholders ask that these damages be monetized in order for them to evaluate benefits and costs associated with alternative management decisions.

The objectives of this study were to 1) Evaluate the silvopastures on Redstone Arsenal for wildlife browse damage to the loblolly pine component and determine the biological relationships with seedling mortality and growth but also with the timing of domestic cattle introduction, 2) Monetize the biological impacts of multiple management scenarios relative to the stated purpose and recommendations for tree and livestock components in a silvopasture system as outlined by Pearson (1984) and Hamilton (2008) and others and, 3) once values for multiple scenarios had been monetized, incorporate scenarios into a net present value (NPV) framework so that alternative decisions could be ranked, compared, and contrasted by relative values.   In the case of Redstone Arsenal, wildlife damage must be monetized as a cost so that potential trade-offs between relative timber and cattle grazing lease values may be evaluated by RSA managers relative to timber and cattle grazing-lease values and decide whether or not to postpone cattle introduction or to introduce under the uncertainty of potential loss in timber value (Godsey 2007; Brauer et al. 2009; Godsey et al. 2009).

3.2. METHODS

3.2.1. Overview of study area

Redstone Arsenal is located in Madison County, Alabama and is home to the United States Army Aviation and Missile Command; see appendix 1 for a state map with the location of Madison County and Redstone Arsenal. The Arsenal is 38,100 acres (59.53 mi^2) in size and positioned near the south-west city limits of Huntsville, Alabama. The Arsenal is home to the Marshall Space Flight Center and U.S. Missile Defense Command.

According to the U.S. Census Bureau (2010), the Huntsville Metropolitan Statistical area has a population of approximately 417,593 people, making it the fourth largest city in the state. Huntsville is geographically located in the Tennessee River Valley and is associated with the Highland Rim and Cumberland Plateau physiographic regions and has a humid subtropical climate and average annual precipitation of 57.5 inches. From 1981-2010, the normal high and low temperatures range from 89.6°F in July to 32.0°F in January (NOAA 2011). In Madison County, Alabama the underlying rock is predominately limestone, sandstone, and some acid shale. According to the United States Department of Agriculture's Natural Resource Conservation Service (USDA-NRCS1993), the primary soil type in Madison County is Decatur silty clay loam (DeB2).

Redstone Arsenal is in the Central Hardwood Forest region which includes Oak-Pine and Oak Hickory forest types (Bailey 1980; Dickson 2001; Gurevitch et al. 2006). Upland forests were comprised of a mixed variety of coniferous and broadleaf deciduous species, with bottomlands being primarily hardwood; see appendix 2 for a list of common woody and non-woody plant species. The total land area encompassed by RSA incorporates a portion of

Wheeler National Wildlife Refuge with common wildlife inhabitants including white-tailed deer, wild turkey, and cottontail rabbits.

The diversity of flora provides quality habitat and aesthetics which promote a range recreational opportunities for private citizens and allow sportsman to harvest game (primarily deer on RSA) with the purchase of a special permit. The deer population density, according to RSA postseason 2009 and preseason 2010 population surveys (conducted by RSA wildlife biologists), averaged 30.12 deer per square mile. The average sex ratio was 38 males per 100 females, and the 2010 preseason recruitment rate of 74 fawns per 100 adult does.

A portion of RSA lands are reserved for agricultural use by private contractors. By partnering with private citizens including local farmers, RSA receives much needed revenue that is generated from agricultural crop and livestock grazing lease fees. In 2011, RSA foresters reported approximately 2,000 acres of pastureland were under cattle grazing leases and an additional 1,500 acres of unused but suitable pastures which they intended to lease. However, a portion of the unused 1,500 acres was being utilized to assess the viability of silvopasture systems for the possibility of producing high-quality timber and enhanced grazing leases on the same land-unit.

3.2.2. Study sites within the larger study area

Within Redstone Arsenal's silvopasture evaluation units, this study examined four loblolly pine silvopastures that were established by RSA foresters in December of 2009. Loblolly seedlings were stocked at 350 trees per acre, on a 6'x 8'x 40' double-row spacing arrangement oriented in an east-west direction. The natural vegetation which grew in all silvopasture alleyways was maintained by RSA personnel through semi-annual mowing.

Each of the four silvopastures was assigned an ascending field identification number which corresponded with descending field area: AGL1 (5.83 acres); AGL2 (4.80 acres); AGL3 (4.17 acres); AGL4 (2.86 acres). For example, Agroforestry Loblolly #1 and was abbreviated as AGL1. All silvopasture sites were previously used by RSA for non-military grazing-leases. Public access is to RSA is restricted, but within RSA, study sites AGL2 and AGL3 were located inside an area of further access restriction. Accessing AGL2 and AGL3 for data collection was contingent upon being granted further clearance by the Arsenal. Security clearance could not be granted more than three days in advance, was subject to the military's discretion; see appendix 3 for a map of the study area and location of study sites.

Study site AGL1 was located on Redstone Road and was bordered to the North by perimeter fencing; to the East was a 2-year old shortleaf pine (*Pinus echinata*) silvopasture planting; to the South was a 2-year old loblolly pine plantation; to the West was mature bottomland hardwoods. Study site AGL2 was located on Anderson Road and was bordered to the North by a 2-year old shortleaf pine silvopasture planting; to the East was a row of woody-shrubs and a strip of mature loblolly pine which ran parallel to both the AGL2 eastern perimeter and to an internal road which ran in a North-South orientation; to the South was a row of woody-shrubs and mature mixed pine/hardwood forest; to the West was a 2-year old loblolly pine plantation.

Study site AGL3 was located on Andersen Road and was bordered to the North by a 2-year old shortleaf pine silvopasture planting; to the East was hedge-row and strip of mature loblolly pine which ran parallel to both the AGL3 eastern perimeter and to an internal road which ran in a North-South orientation; to the South was a row of woody-shrubs and mature mixed pine/hardwood forest; to the West was a 2-year old loblolly pine plantation. Study site AGL4 was located on Macalpine Road and was bordered to the North by a 2-year old shortleaf pine silvopasture planting; to the East was perimeter fencing; to the South was a small wildlife food plot where soybeans were planted during the summer months; to the West was a row of woody-shrubs and mature mixed pine/hardwood forest.

3.2.3. Study approach and techniques

This study was designed to collect a 10% representative sample of seedlings in each silvopasture, using the systematically-randomized line-transect method. Due to the lack of data on this topic, the study combined techniques from the sciences of forestry, wildlife biology, and wildlife damage economics. The purpose of combining these techniques was to systematically collect a representative of average seedling height, prior to cattle introduction according to, yet incorporate an element of simple random design to assess the seasonality and spatial characteristics of asymmetric wildlife movements and foraging behavior (Pearson 1984; Shelton and Cain 2002; Hamilton 2008). These methods were combined in a way so that data could be evaluated both biologically and economically, similar to the methods used by both Shelton and Cain (2002) and Godsey and Dwyer (2008). Other observational data resulting from this study design were collected to provide descriptive include: soil samples, field perimeter and plant structure characteristics, observations of other animal and non-animal loblolly seedling damages. This study was conducted according to four main tasks:

Task 1. Assess four silvopastures on Redstone Arsenal, collecting data that included loblolly seedling mortality, seedling heights and growth, wildlife browse damage severity and seasonality, and other observational field data to assist with habitat and study site descriptions.

Task 2. Obtain 2009 and 2013 financial data from the appropriate personnel at Redstone Arsenal that included revenue, cost, and time variables associated with the production of trees, cattle, and hay.

Task 3. Using IBM SPSS Statistics19 (IBM 2012), conduct analysis of variance to identify relationships between the dependent variable (seedling height in December of 2011) and independent variables (study site and wildlife browse damage category).

Task 4. Using PTAEDA 3 software (Burkhart et al. 2003), field and wildlife browse damage data, and average seedling height in December of 2011, simulate one year of additional seedling growth to estimate an average height range for seedlings in December of 2012, when seedlings are 3-years old. Compare the 2012 seedling height projections to the minimum heights recommended for livestock introduction in southern pine silvopastures (Pearson 1984; Hamilton 2008).

Task 5. Based both on the proportion of seedlings that were projected not to satisfy the 2012 height requirements and the financial data which were collected by this study, use the replacement cost approach and general discounting methods to calculate the 2012 financial values of three production options involving tree, cattle, hay, components. Use net present value (NPV) framework to analyze the change in NPV per acre ($/acre) that is associated with each management option and identify the proportion of value change that is associated with wildlife browse damage to young trees.

3.2.4. Task 1 - Design implementation and biological data collection

For Task 1, there were a total of five data collection periods. The first data collection period coincided with the study implementation. The implementation phase occurred over seven non-consecutive days in late February and early March of 2011 (prior to the start of growing season) due to military exercise security restrictions surrounding study sites AGL2 and AGL3. Thereafter, the second, third, fourth and fifth (final) data collection period occurred in May, July, September, and November of 2011 respectively.

Design implementation began by first establishing a sampling grid, comprised of line-transects and seedling plots, in each of the four silvopasture study sites; all line-transects were oriented in a north-south direction that traversed the double-rows in a perpendicular direction relative to the east-west orientation of loblolly seedling rows. Within each grid, the south-east corner of planted loblolly seedlings was randomly assigned to serve as the starting point for systematically laying out the sampling grid. Beginning at the south-east corner, using a (Keson NR10100) 100 foot measuring tape, a distance of 33feet was measured while pacing due-west along the southern perimeter of loblolly seedlings. The point, representing a distance of 33feet, was marked with a bamboo stake; this point served as the south end-point of the first line-transect.

While standing at the south end-point of the first line-transect, a compass was used to determine the azimuth of due-north and identify a fixed focal point. After traversing the length of the first line-transect, a bamboo stake was placed on perimeter of the northern most seedling row; the two stakes served as the end-points which delineated the first line-transect. Beginning from the northern end-point of the first line-transect, a distance of 66feet was measured while pacing due-west along the northern perimeter of loblolly seedlings. The point, representing 66feet, was marked with a bamboo stake; this point served as the north end-point of the second line-transect.

From the north end-point of the second line-transect, a compass was used to determine the azimuth of due-south and identify a fixed focal point. After traversing the length of the second line-transect, a bamboo stake was placed on the perimeter of the southernmost seedling row; the two stakes served as the end-points which delineated the second line-transect. Each succeeding line-transect was separated by a distance of 66feet and the process of delineating line-transects proceeded in precisely the same manner, moving from east to west, until reaching line-transects could no longer be separated by 66 feet when approaching the western perimeter of the silvopasture.

Second, after delineating all line-transects, loblolly seedling plots were identified for measurement and visual assessments. For the purpose of this study, a "seedling plot" or just "plot" consisted of two seedlings. There was one "seedling plot" per double-row set of seedlings, and the number of seedling plots per line-transect was directly determined by the number of double-row sets of seedlings which were traversed by that line-transect. For example, if one line-transect traversed twelve double-row sets of seedlings, then twelve plots (24 seedlings) were identified for evaluation.

Third, each plot was identified by a combination of unique field-plot number and GPS coordinates, for example, the first plot in silvopasture AGL1 was identified by the field-plot number "AGL1-001." Moving north along the line-transect, the second plot was AGL1-002. The third plot was AGL1-003. All GPS coordinates which were collected using a TDS Nomad system with SOLO Forest GIS mapping software. Plot locations were collected and joined with digital maps provided by the Arsenal's GIS specialist. Resulting maps were projected to North American Datum 1983 (NAD 83), Universal Transverse Mercator Zone 16 (UTM 16).

Because of the double-row silvopasture design, to reduce sampling bias (after having randomly selected the southeast corner of each silvopasture to serve as the starting point of the first line-transect), each plot location alternated between the north and south row of seedlings.

As a result, the distance between plots along each transect alternated between 56' feet and 40feet respectively. The difference in spacing is due to the width of 8feet between individual seedling rows, the alley width of 40 feet between each set of double rows, and the plot alternation. This linear method of plot identification was precisely repeated in each of the silvopasture study sites.

Fourth, after identifying all seedling plots, the two loblolly seedlings in field-plot location were identified individually as "treatment" and "control" seedlings. For example, AGL1-001 "treatment" seedling and AGL1-001 "control" seedling. Finally, the seedling located on the east-side of each plot was randomly selected and designated as the "treatment." Thus, the seedling located on the west-side of each plot as the "control". For example, "AGL1-001 treatment" was the seedling located on the east side of the first plot, located on the southernmost row at the south end-point of the first line-transect, approximately 33 feet from southeast corner the first silvopasture study site (AGL1). This method of field, plot, and seedling identification was replicated precisely the same way for all seedling plots.

3.2.4. Task 1 (continued). Biological data collection

After design implementation was completed and all seedling plots were identified, data collection began. First, seedlings were assigned a yes or no response to an initial characterization as being alive or not alive, and were visually assessed for browse damage. "Alive" designations were defined as seedlings which were still rooted, with foliage showing signs of photosynthetic capability. "Not alive" designations were defined either as seedlings with or without foliage but showing no visible signs of photosynthetic capability or those seedlings which were not still rooted. If a seedling was missing from a plot where the management forester indicated that one had been planted or where a seedling had been observed and recorded in the previous data collection period then it was recorded as “missing”.

Second, seedling heights were measured twice, once during the initial data collection and once during the final data collection. Seedling height data were categorized as “beginning seedling heights” and “ending seedling heights respectively.” The height of all seedlings was measured to the nearest inch. Seedling height was measured as the vertical distance from ground-line to the apical meristem (terminal bud). Ending height measurements were not recorded for seedlings with the mortality classification as “not alive.” Thus ending heights were recorded only for seedlings with mortality status “alive.”

Third, all seedlings, whether alive or dead, were assigned a “yes” or “no” response to a characterization as having been browsed or damaged. Any seedlings that had been browsed were assigned the following responses in accordance with the literature to indicate browse damage from deer (DR) or rabbits (RB) (Curtis and Sullivan 2001; Dickson 2001; Conover 2002). Browse damage that could not be clearly identified as either that of a deer or rabbit was categorized as deer and rabbit (DR/RB). Following methods similar to Shelton and Cain (2002) regarding the severity of damage, the location of browse damage on loblolly seedlings was categorized as either “Lat” for lateral stem damage, “Term” for terminal bud damage or “Term/Lat” for terminal bud and lateral stem damage. All other damage forms were categorized as Other (OT). Other forms of non-browse damage included pine tip moth (*Rhyacionia frustrana*), Fusiform rust (*Cronartium quorum f. sp. fusiforme*), soil excavations by animals such as the nine-banded armadillo (*Dasypus novemcinctus*), and mechanical damage from farm equipment.

Fourth, after all initial data were recorded, seedlings designated as “treatments” were enclosed within Rigid Seedling Protector Tubes (measuring 48 inches in height and 6 inches in diameter) which were then secured to a bamboo stake (measuring 60 inches in length and 1 inch diameter) with a zip-tie. Rigid Seedling Protector Tubes were photodegradable and fashioned as perforated mesh so that seedlings received full sun-light and to reduce the possibility of a microclimate around the seedlings. Treatment seedlings were protected and control seedlings were unprotected in an attempt to detect potential relationships between the growth rates of undamaged loblolly seedlings and the following variables: severity of damage, seasonality of damage, repetitious or multiple damages, and differing wildlife species.

Fifth, soil samples were collected from 20 random locations in each of the four study sites. Beginning at the southeast corner of each site, samples were collected from random locations by walking across each field in an alternating angular (zig-zag) pattern (Brady and Weil 2002). Using a stainless steel hand trowel and bucket, vertical slices of the top 2 to 3 inches of soil were collected at each sampling location (Brady and Weil 2002). The hand trowel and bucket were cleaned before sampling began in each field to reduce possible contamination. All soil samples were analyzed by the Auburn University Soil Testing Laboratory located in the ALFA Agricultural Services and Research Building on the Auburn University campus.

The study design resulted in the seedling and wildlife browse damage data being collected from a total of 309 plots across four sites (AGL1=102 plots; AGL2 = 84 plots; AGL3 = 73 plots; AGL4 = 50 plots). The total number of seedlings examined was N = 618 (309 plots x 2 seedlings/plot = 618 seedlings). Table 3.1 provides a summary of the biological data that were collected from four loblolly pine silvopasture sites on Redstone Arsenal in Madison County, which began in February of 2011 and concluded in November of 2011 at which time seedlings were 2-years old.

Table 3.1. Description of biological data that were collected between February of 2011 and November of 2011 from four loblolly pine silvopasture sites on Redstone Arsenal in Madison County, Alabama.

Study site (Field)	Seedling Mortality Category	Wildlife Browse Damage Category	Mean Initial Seedling Height Measurements in February of 2011	Mean Ending Seedling Height Measurements in November of 2011	Other Data
AGL1 AGL2 AGL3 AGL4	*Alive Not-Alive	No damage (category-1 = least severe) Lateral Stem Damage (category-2 = mild severity) Terminal Bud Damage (category-3 = medium severity) Terminal Bud & Lateral Stem Damage (category-4 = high severity)	Height measurement of all seedlings (inches) recorded during the first data collection period in February of 2011	Height measurement of all seedlings (inches) recorded during the final data collection period in November of 2011- (*Note: ending heights were measured for "Alive" seedlings only)	Other damage soil samples descriptive data for surrounding habitat

3.2.5. Task 2 - Financial data collection

Cost and revenue data were also collected during the fall of 2011. The RSA managing forester reported the establishment cost of $107/acre, in December of 2009, for 350 stems/acre double-row loblolly pine silvopasture; the establishment cost included the price of seedlings, site-prep, labor and one release-spray. The expected annual revenue from private contractors (lessees) for cattle-grazing leases was reported to be $20/acre, with leases beginning in 2013.

Fencing materials were reported to be in place and that lessees are obligated for annual fence maintenance costs. Hay production in silvopasture alleyways was reported as management alternative to cattle leases. The expected annual quantities, revenue, and costs generated by "in-house" hay production, were reported to be 6 hay-bales/acre (3 hay-bales/acre/twice per year), $25/bale. The reported cost of hay production was $15/bale harvesting cost, with production beginning in 2013. Table 3.2 lists nominal values for cost and revenue data that were collected in 2011 for the assessment of silvopasture tree, forage (hay), and livestock (cattle) components of four loblolly pine silvopastures on Redstone Arsenal in Alabama.

Table 3.2. Revenue and cost data collected in 2011 for assessment of tree, forage (hay), and livestock (cattle) components of four loblolly pine silvopastures on Redstone Arsenal in Alabama.

Year	Activity	Cost ($/acre)	Revenue ($/acre)
2009	Stand establishment	$107/acre	---
2013 - 2015	Fence est/maint	---	---
2013 - 2015	Animal maintenance	---	---
2013 - 2015	Cattle grazing lease	---	$20/acre
2013 - 2015	*Hay production	$90/acre	$150/acre

* Indicates that producing hay and grazing cattle on the same acreage are considered to mutually exclusive uses. RSA personnel indicated that the decision for cattle introduction will made in December of 2012

3.2.6. Task 3 - Analysis of biological data

The statistical packages IBM SPSS Statistics (IBM 2012) was used to analyze biological data that were summarized in table 3.1 which included study site, seedling mortality category, wildlife browse damage category, and mean ending seedling height. First, following methods similar to Shelton and Cain (2002), analyses were conducted using a one-way analysis of variance (ANOVA) to examine statistical relationships between seedling mortality category (dependent variable) and wildlife browse damage category (independent variable). Second, the entire data set was split by seedling mortality category (“alive”; “not-alive”) because ending height measurements were only recorded for the seedlings which were alive during the final data collection period in November of 2011. Third, for seedlings that were alive, analyses used the general linear model (GLM) procedure in the SPSS statistical package to conduct analysis of variance (ANOVA) between mean ending seedling height (dependent variable) and the independent variables (field; wildlife browse damage category).

The first independent variable was “Field” which had four levels: AGL1; AGL2; AGL3; AGL4. The second independent variable was “wildlife browse damage category” which had four levels (category-1 = no browse damage; category-2 = lateral stem browse damage; category-3= terminal bud browse damage; category-4 = terminal bud and lateral stem damage). The four levels of wildlife browse damage were based on methods used by Shelton and Cain (2002) and Godsey and Dwyer (2008) respectively, in order to categorize the severity of rabbit browse damage to loblolly pine seedlings and to categorize the severity of deer rubbing damage to black-walnut trees.

Fourth, following methods similar to Shelton and Cain (2002), PTAEDA 3 software (Burkhart et al. 2003) and the November-2011 mean ending seedling height for each of the four levels of wildlife browse damage category, were used to project one additional year of seedling growth to represent the average seedling height of each level one-year later in 2012. The PTAEDA 3 software program provides users with a growth and financial evaluation model for analyzing intensively managed loblolly pine plantations (Burkhart et al. 2003). PTAEDA 3 was developed using region-wide growth data from loblolly pine trees growing in un-thinned site-prepared plantations; trees are grown annually as a function of their size, the site quality, site preparation treatments and the competition from neighbors (Burkhart et al. 2003).

To accomplish this simulation, the 2011 - mean ending seedling height for the four levels of wildlife browse damage category were individually entered in to PTAEDA 3 as the "beginning mean seedling height" for the 2012-growing season. Other input variables were stand age (2-years) and trees per acre of 908. This was chosen to represent the approximate, equivalent stocking of a 6'x8'x40' double-row silvopasture at 350 trees per acre and to mimic competition factors (Grado et al. 2001; Husak and Grado 2002). The site-index was input as 65, which was obtained from the forester at Redstone Arsenal who manages the silvopastures. The resulting 2012 height estimations were then compared against the seedling height recommendations in Pearson (1984) and Hamilton (2008) for cattle introduction into the southern pine silvopastures (5, 6, or 7 feet). Table 3.3 provides a categorical summary of the process for how the average seedling height for each of the four levels of wildlife browse damage category recorded for December of 2011 will be projected to grow for one year, resulting in four corresponding average seedling heights in December of 2012 that are compared to the heights 5, 6, and 7 feet which are the recommended minimum heights for cattle introduction.

Table 3.3. Categorical description of how average seedling height data in four loblolly pine seedling/damage groups in 2011, growth simulation methods, and PTAEDA 3 loblolly growth software were used and resulted in four corresponding height estimates for those groups in December of 2012.

Seedling Mortality Category	Observed Mean Height of Loblolly Seedlings by Wildlife Browse Damage Category (Levels) in December of 2011	Projected Mean Height of Loblolly Seedlings by Wildlife Browse Damage Category (Levels) in December of 2012 when Cattle are Introduced	Recommended Minimum Seedling Heights for Cattle Introduction into Silvopastures **(Pearson 1984; Hamilton 2008)**
Alive	Observed mean height of seedlings with no damage (category-1) in December of 2011	Mean height of damage category-1 seedlings in December of 2012 when Cattle are Introduced	Recommended minimum seedling heights are **5, 6, or 7** feet
Alive	Observed mean height of seedlings with lateral stem damage only (category-2) in December of 2011	Mean height of damage category-2 seedlings in December of 2012 when Cattle are Introduced	Recommended minimum seedling heights are **5, 6, or 7** feet
Alive	Observed mean height of seedlings with terminal bud damage only (category-3) in December of 2011	Mean height of damage category-3 seedlings in December of 2012 when Cattle are Introduced	Recommended minimum seedling heights are **5, 6, or 7** feet
Alive	Observed mean height of seedlings with both terminal bud & lateral stem damage (category-4)	Mean height of damage category-4 seedlings in December of 2012 when Cattle are Introduced	Recommended minimum seedling heights are **5, 6, or 7** feet

3.2.7. Task 4 – Replacement cost approach, discounting, and net present value

First, the loblolly seedling establishment cost ($/acre) for silvopastures on Redstone Arsenal (RSA), which is summarized in table 3.2, was manually incorporated into the replacement cost approach following methods outlined by Zhang and Pearse (2011). All replacement cost calculations of seedling value per acre ($/acre) followed equation 1 (Zhang and Pearse 2011). Equation 1. $\mathbf{V_n = V_0 (1+i)^n}$ (eq. 1) where:

- V_n = the present value of the investment

- V_0 = the establishment cost at year 0
- (1+i) = the interest rate of return
- n = number of years or periods since establishment

Because value is relative to the stakeholder, the nominal interest rates of 3%, 6%, and 9% were selected for use in all financial calculations in order to yield a relative range of values that reflect a diverse, yet reasonable range of expectations concerning the value per acre ($/acre) of the pre-merchantable tree component of the silvopastures on Redstone Arsenal (RSA). The interest rates (3%, 6%, and 9%) were based on similar rates of interest that are earned by alternative investment opportunities such as corporate bonds, common stock equity, annuities, or another land management practice (Grado et al. 2001; Husak and Grado 2002; Godsey 2007; Fleuriet 2008; Zhang and Pearse 2011). The alternative investment opportunities represent the "opportunity costs" with regards to the time-value of the money that RSA invested in the tree component of silvopastures via the seedling establishment cost, and the corresponding rate of return associated with what the money (establishment cost) could have been reasonably expected to earn if it had been invested in one of the alternatives (Ward et al. 2004; Zhang and Pearse 2011).

Please note that these interest rates are considered pre-tax returns both to provide a broader range of applicability and due to unknown tax structures regarding the U.S. Army and the private contractors who may or may not graze cattle on RSA silvopastures (Husak and Grado 2002; Godsey 2007; Godsey et al. 2009; U.S. Trust 2010; Zhang and Pearse 2011). However, the benefits and rate of return that could be expected from producing a high-quality timber component in a silvopasture system, based on the silvopasture literature, were also considered to be reasonable expectations (Husak and Grado 2002; Godsey et al. 2009; U.S. Trust 2010; Zhang and Pearse 2011). These values included: future timber revenues; premium cattle-grazing leases due to reduced cattle production costs that result from tree shade; hunting leases or permit fees; reduction of soil erosion, improved water quality, and increased bio-diversity; or combinations of the previous expectations such as future timber revenue, premium cattle-grazing leases, and increased bio-diversity (Grado et al. 2001; Husak and Grado 2002; Godsey 2007; Godsey et al. 2009; U.S. Trust 2010; Zhang and Pearse 2011).

Interest rates were chosen to represent rates of return that are similar to the following investment objectives: **3% interest rate** = average nominal rate of return from a 30-year U.S. Government bond, could be conservatively expected for future timber value, and is also the nominal rate needed to preserve the real or par value of money from being eroded by annual inflation; **6% interest rate** = 1991- 2009 average nominal rate of return on pine saw-timber or the 10-year average rate of return on the S&P 500 (2002 – 2012); **9% interest rate** = the 20-year average rate of return on the S&P 500 (1987 – 2007) or a composite rate of return reflecting expectations concerning the total rate of return generated by a high-quality timber component in a complete silvopasture system over the length of a 25-year rotation including revenue from future pine-saw timber revenues plus future premium cattle grazing leases due to tree shade reducing cattle production costs plus revenue from improved hunting permit fees, cost-share programs, and tax incentives (Graham 1949; Grado et al. 2001; Husak and Grado 2002; Ward et al. 2004; Hamilton 2008; Godesey et al. 2009; Zhang and Pearse 2011). Table 3.4 summarizes the selection of interest rates of 3%, 6%, and 9% based on conservative opportunity costs or expectations concerning the financial benefits of a silvopasture tree component (Grado et al. 2001; Husak and Grado 2002; Godsey 2007; Godsey et al. 2009; Zhang and Pearse 2011).

Table 3.4. Basis for interest rates used in the replacement cost approach to assign a monetary value to the pre-merchantable timber component of silvopastures on Redstone Arsenal in Alabama. The interest rates of 3%, 6%, and 9% were used to reflect the opportunity costs of the financial capital that was invested in seedling establishment (the rates of return return associated with what the money could have been reasonably expected to earn if it had been invested in one of the alternative investments), the expected rates of return associated with the production of timber in a silvopasture system.

Interest Rate (%)	Opportunity Cost of Money Invested (seedling establishment cost) in the Timber Component of a Silvopasture	Expected Returns on Timber Component of Silvopasture
(3%)	30-year U.S. Government Bond earning annual interest of 3%	Expectation for modest return on timber and reduced cattle production costs
(6%)	10-year average rate of return on the S&P 500 (2002 – 2012)	1991- 2009 average rate of return on pine saw-timber
(9%)	< 20-year average rate of return (12.7%)on the S&P 500 (1987 – 2007)	Composite rate of return on a high-quality timber, benefits for cattle, hunting leases, and tax incentives

First, using each of the interest rates separately, the 2009 seedling establishment cost was translated into the following forms using the replacement cost approach. 1) Seedling value per acre in 2011 was calculated using by compounding the establishment cost for two years (2009 – 2011) using equation 1, in order to represent the seedling value per acre ($/acre) in 2011. 2) The 2011 seedling mortality per acre was used to reflect the 2011 seedling value ($/acre) that was lost due to seedling mortality. The product of multiplying the 2011 replacement value ($/acre) by the percentage of seedling mortality per acre resulted in the cost ($/acre replacement value loss) of seedling mortality.

This cost of seedling mortality was used to reflect either the 2011 cost of replanting the seedlings, the opportunity cost of that money invested elsewhere or the forgone benefits that may have been expected from the trees in silvopasture as they mature. For example, if the seedling mortality is expressed as a ratio of the initial stocking which was 350 trees per acre, then the following holds true where: 35 seedlings per acre are recorded as “not-alive” for the year ending December 31, 2011; 35 trees per acre/350 tree stocking = 10% loss of trees per acre = 10% loss of 2011 replacement value per acre. In this case, the 2011 seedling mortality per acre (“not-alive”) is paralleled precisely the 2011 cost per acre due to tree mortality (loss in replacement value per acre). This cost was then considered an irretrievable cost or “sunk-cost” and was not used in the net present value calculations; not because the mortality cost was unimportant but rather because, in 2012, RSA could not manage for the loss which had already occurred. In 2012, the decision to introduce cattle was based on the value trade-offs between tree, cattle, and forage components which had not yet occurred and could still be managed.

3) For the evaluation of seedling value in 2012 at the time of cattle introduction, the 2009 establishment cost per acre was compounded for three years (2009 – 2012) using equation 1, to represent the 2012 replacement value per acre ($/acre) for seedlings at 3-years of age. 4) The percentage of 2012 seedling replacement value per acre that was considered to be at-risk for cattle introduction in 2012 was directly proportional the percentage of seedlings per acre below the minimum recommended heights for cattle introduction based on the PTAEADA 3 growth simulations for 2012 in comparison the minimum heights recommended for safe cattle introduction (Pearson 1984; Hamilton 2008). This study uncovered no data related to expected seedling mortality rates due to cattle introduction, therefore it was unknown if all of the “at-risk” seedlings would be lost. As a result, five different cattle damage scenarios were examined regarding loss of seedling replacement value per acre ($/acre) within the larger management option to “introduce cattle” where: a) no at-risk seedlings were lost; b) one-quarter of at-risk seedlings were lost; c) one-half of the at-risk seedlings were lost; d) three-quarters of the at-risk seedlings were lost; e) all at-risk seedlings were lost.

Second, following the 2012 value (V_0) per acre ($/acre) for the revenue and costs associated with 2013 cattle leases and hay production were calculated by discounting their 2013 value (V_n) for one year using 3%, 6%, and 9% as discount rates (Zhang and Pearse 2011). Because costs and revenues associated with timber, forage, and cattle components occurred at different times, they had to be transformed into the same time-value (2012) in order to compare potential value trade-offs at between system components at the time cattle are introduced (Schwiff 2004; Zhang and Pearse 2011). Single-year discounting calculations for grazing lease and hay production followed the general form equation 2. Discounting revenue and costs for more than one year of cattle grazing leases and hay production followed equation 3.

Equation 2. $\mathbf{V_0 = V_n/(1 + i)^n}$ (eq. 2) where:

- V_0 = present value/acre in year 0
- V_n = the future value in year n
- (1+i) = the discount rate
- n = number of years in the period

Equation 3. $\mathbf{V_0 = a[(1+i)^n - 1]/i(1+i)^n}$ (eq. 3) where:

- V_0 = the present value of annual livestock revenue/acre.
- a = the annual revenue/acre.
- (1+i) = the discount rate.
- n = the number of years in the period.

Third, after having calculated all of the 2012 values/acre ($/acre) associated with the silvopasture components and potential trade-offs under consideration, the 2012 present values per acre (PV/acre) were incorporated into the net present value (NPV) framework. The NPV framework was used to identify the net present value per acre (NPV/acre), and any subsequent changes of NPV/acre, in order to rank and compare the benefits and costs ($/acre) associated with three management options. The three management options examined were: 1) postpone cattle with no hay production; 2) introduce cattle (no hay production) given the different cattle damage scenarios within this option; 3) postpone cattle, produce hay, and allow "at-risk" seedlings to grow an additional year before cattle introduction is reconsidered. Along with all other relevant considerations, estimating the NPV/acre allowed for the relative examination of trade-offs between timber, forage and cattle values that were associated with management alternatives and available data. All net present value calculations followed equation 4 (Godsey et al. 2009; Zhang and Pearse 2011). Equation 4. **NPV = PVR - PVC** (eq. 4) where:

- NPV = the net present value in 2012.
- PVR = the present value of revenues in 2012
- PVC = the present value of costs in 2012

3.3. RESULTS

Following the study design, the number and distribution of initial seedling observations by mortality category (alive; not-alive; missing) across all silvopasture sites in February of 2011 were alive = 442 (71%), not-alive = 90 (15%), and missing = 86 (14%). Table 3.5 and Table 3.6 list the initial seedling height data by mortality categories (alive; not-alive) and wildlife browse damage categories respectively for alive and not-alive and report their respective initial mean height measurements, standard deviation, and height range from minimum recorded height to the maximum recorded height. Figure 3.1 shows the distribution of seedling observations by mortality category and across the four silvopasture sites on Redstone Arsenal in November of 2011.

After initial seedling heights recorded in February of 2011, repeated browse damage events were observed on less than 1% of all control seedlings during the second data collection period in May of 2011, and there were no repeated damage observations during the third, fourth, or final data collection periods (July-2011; September-2011; November-2011). It appears then that more than 99% of the wildlife browse damage to seedlings occurred within the first year from planting (2009 – 2010), prior to the first data collection period in February of 2011.

Table 3.5. Initial seedling height data by mortality category (alive; not-alive) for all silvopasture sites on Redstone Arsenal in February of 2011.

Mortality Category	Number of Seedlings	Mean Seedling Height (inches)	Standard Deviation (inches)	Minimum Height (inches)	Maximum Height (inches)
Alive	442	16.06	3.57	5	31
Not-Alive	90	10.61	3.56	3	19

Table 3.6. Initial seedling height data by mortality and wildlife browse damage categories for all silvopasture sites on Redstone Arsenal in February of 2011.

Mortality Category	Wildlife Browse Damage Category (Levels 1 – 4)	Number of Seedlings	Mean Seedling Height (inches)	Standard Deviation (inches)
Alive	1 = No damage	101	18.27	3.60
	2 = Lateral stem damage	159	17.57	2.37
	3 = Terminal bud damage	71	14.29	2.05
	4 = Terminal bud and lateral stem damage	111	13.03	3.09
Not-Alive	1 = No damage	5	10.79	4.67
	2 = Lateral stem damage	2	15.16	1.95
	3 = Terminal bud damage	19	12.45	2.42
	4 = Terminal bud and lateral stem damage	64	9.91	3.55

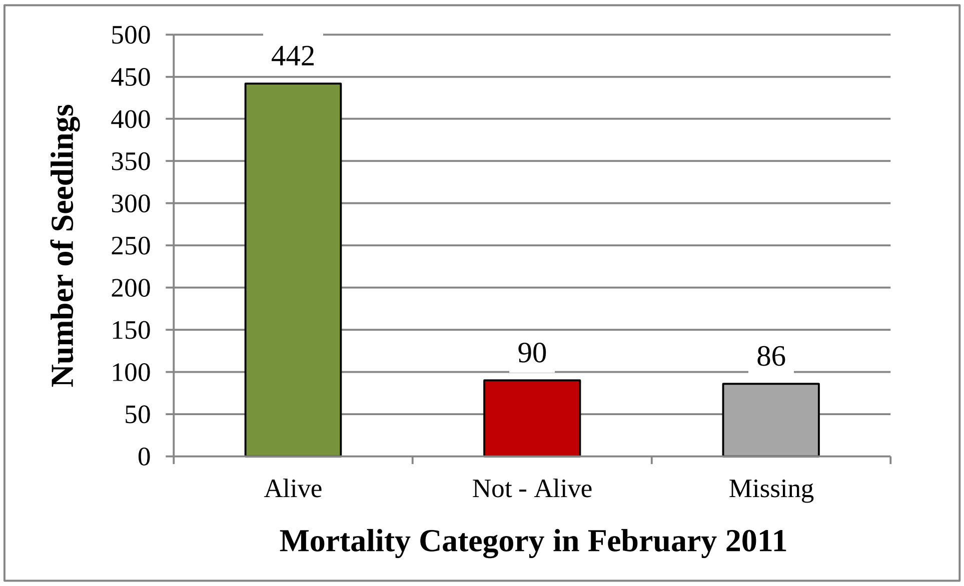

Figure 3.1. Number (N = 618) and distribution of seedling observations by mortality category for all silvopasture sites (AGL1; AGL2; AGL3; AGL4) on Redstone Arsenal in February of 2011

By the conclusion of data collection in November of 2011, 18 of the original 442 seedlings which were categorized as alive lost all visual indication of photosynthesis and were re-categorized as not-alive. The number and distribution of ending seedling observations by mortality category in November of 2011 were alive = 424 (69%), not-alive = 108 (17%), and missing = 86 (14%), respectively. Table 3.7 lists the ending seedling observations by mortality categories alive and not-alive and report their respective initial mean height measurements, standard deviation, and height range from minimum recorded height to the maximum recorded height. The total number, mean ending height, and standard deviation of seedlings classified as "alive" were: N = 424; X = 39.99in.; s.d. = 11.51in. Figure 3.2 shows the distribution of seedling observations by mortality category and across the four silvopasture sites on Redstone Arsenal in November of 2011.

Table 3.7. Ending seedling height data by mortality category (alive; not-alive) for all silvopasture sites on Redstone Arsenal in 2011

Mortality Category	Number of Seedlings	Mean Seedling Height (inches)	Standard Deviation (inches)	Minimum Height (inches)	Maximum Height (inches)
Alive	424	39.99	11.507	9	89
Not-Alive	108	---	---	---	---

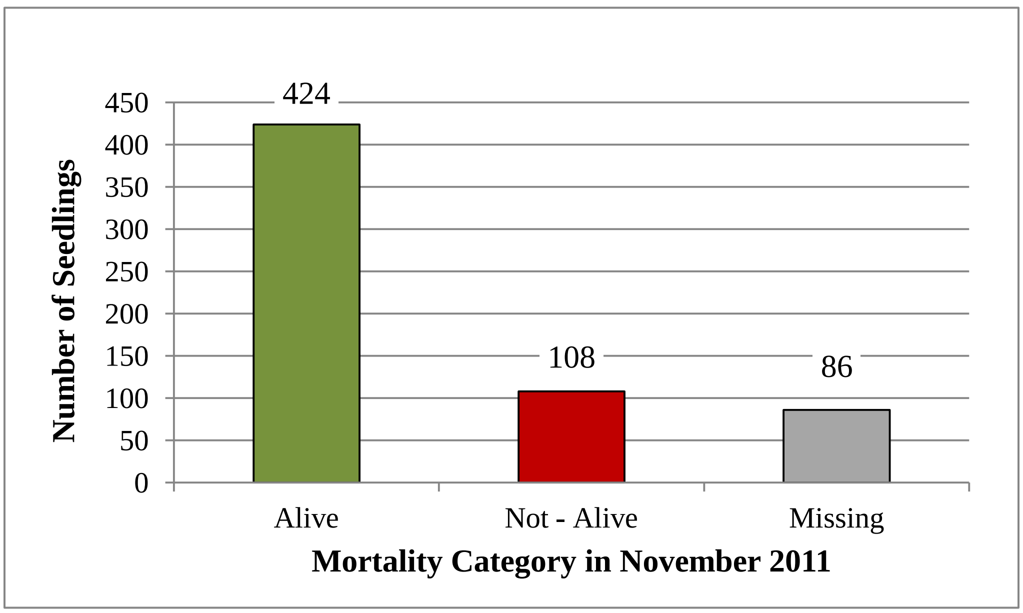

Figure 3.2. Number (N = 618) and distribution of seedling observations by mortality category for all silvopasture sites (AGL1; AGL2; AGL3; AGL4) on Redstone Arsenal in November of 2011

The observations for seedling mortality category within each silvopasture site on Redstone Arsenal in 2011 are listed in Table 3.8 and were as follows: AGL1 (5.83 acres); AGL2 (4.80 acres); AGL3 (4.17 acres); AGL4 (2.86 acres). Figure 3.3 and Figure 3.4 show the distribution and proportion of seedling observations within mortality category “not-alive” by wildlife browse damage category levels for all silvopasture sites on Redstone Arsenal in November of 2011. The percent seedling mortality by damage category was as follows: category-1 (N = 10; 9.26%); category-2 (N = 6; 5.56%); (N = 21; 19.44%); (N = 71; 65.74%). Interactions between variables for wildlife browse damage category, missing seedlings, and not-alive seedlings were not analyzed for the purpose of seedling height at the time of cattle introduction due to many influences and potentially confounding variables which included other forms of animal damage and competition from vegetation that surrounded the pine seedlings. For the purpose of the economic analyses, seedlings were considered to be definitively “not-alive” only if they showed no visible signs of photosynthesis during the final data collection period in November of 2011, even if they were recorded as not-alive during all five collection periods because they can re-sprout foliage (Hunt 1968; Shelton and Cain 2002).

Table 3.8. Study site, mortality category, frequency, and percent of observations within each silvopasture study site on Redstone Arsenal in 2011.

Study Site	Seedling Mortality Category	Number of Seedlings	Percentage of Seedling Mortality Observations Within Study Sites - (%)
AGL1 (5.83 acres)	Alive	164	80.0%
	Not Alive	18	9.0%
	Missing	22	11.0%
	Total	204	100.0%
AGL2 (4.80 acres)	Alive	108	64.0%
	Not Alive	38	23.0%
	Missing	22	13.0%
	Total	168	100.0%
AGL3 (4.17 acres)	Alive	102	70.0%
	Not Alive	27	18.0%
	Missing	17	12.0%
	Total	146	100.0%
AGL4 (2.86 acres)	Alive	50	50.0%
	Not Alive	25	25.0%
	Missing	25	25.0%
	Total	100	100.0%

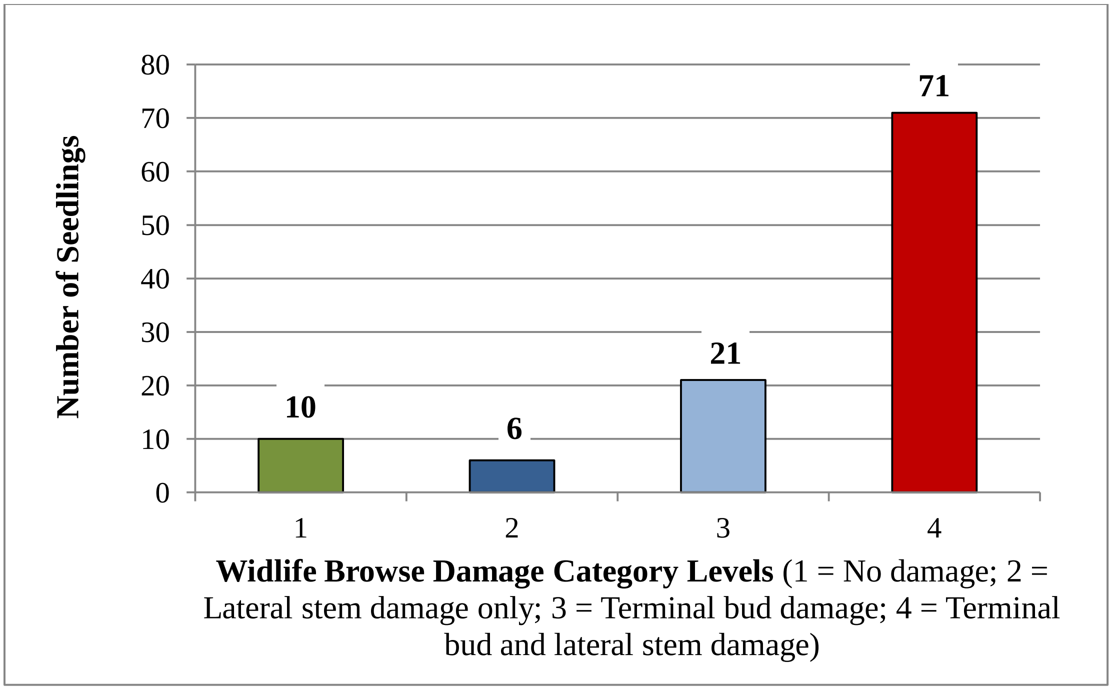

Figure 3.3. Total number and distribution of seedlings in mortality category "not-alive" by wildlife browse damage category levels for all silvopasture sites on Redstone Arsenal in November of 2011

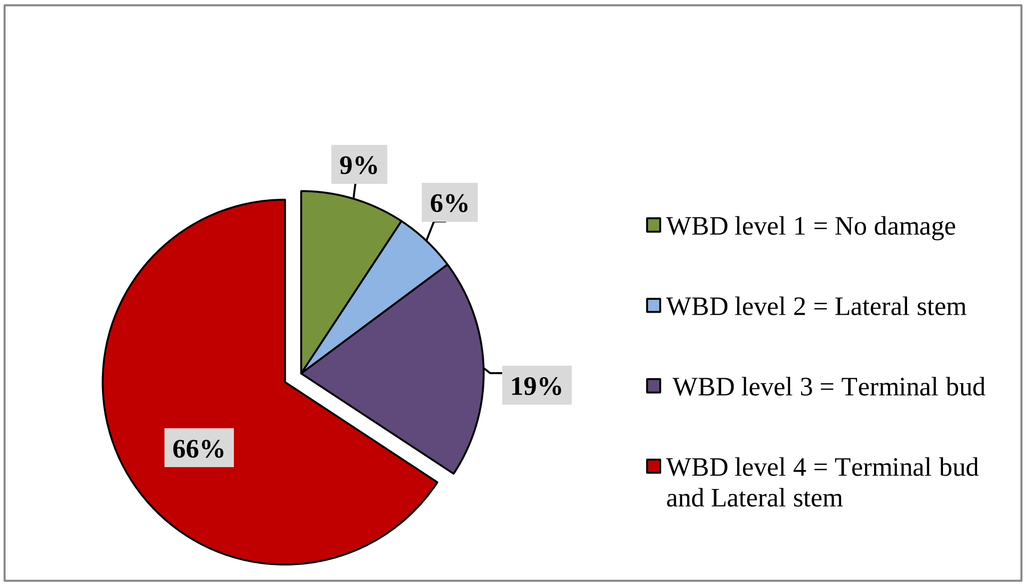

Figure 3.4. Proportion of observations within seedling mortality category "not-alive" by wildlife browse damage category levels for all silvopasture sites on Redstone Arsenal in November of 2011

Due to the small individual acreages of study sites, the soil analysis results (resulting soil pH values for each study site were: AGL1 = 6.3; AGL2 = 6.3; AGL3 = 6.0; AGL4 = 6.7), similarity of surrounding habitat, and other variable associated with location of the overall study area, statistical analyses did not include field specific data. As a result, this study could neither measure the height of seedlings prior to the initial damage nor differentiate the timing of individual seedling damage during the 13-months between establishment in December of 2009 and February of 2011. Furthermore, the time interval between seedling establishment and the first data collection period resulted in difficulties for the accurate identification and distinction between browse damage caused by either a deer or rabbit as well as determining whether or not a particular seedling had been repeatedly browsed during the 1st growing-season.

Therefore all browse damage was collectively categorized as "wildlife browse damage." The total number and percentage of observations, ending mean seedling height, and standard deviation of mean heights for seedlings in mortality category "alive" in all silvopasture sites on Redstone Arsenal in November of 2011 are listed by wildlife browse damage category in Table 3.9 and were as follows: wildlife browse damage category-1 (*N* = 96; 22.64%; $\bar{x}$ = 47.5in.; s.d. = 10.96in.); wildlife browse damage category-2 (*N* =155; 36.56%; $\bar{x}$ = 45.8in.; s.d. = 7.61in.); category-3 (*N* = 69; 16.27%; $\bar{x}$ = 31.8in.; s.d.= 6.3in.); category-4 (*N* = 104; 24.53%; $\bar{x}$ = 29.8in.;s.d. = 8.02).

Table 3.9. Summary of data for seedlings that were still alive at the conclusion of data collection in November of 2011 by wildlife browse damage category, number of seedlings, ending mean seedling height, and standard deviation of seedling heights across all silvopasture sites on Redstone Arsenal.

Browse Damage Category Levels	Number of Seedlings "Alive"	Mean Ending Seedling Height (Inches)	Standard Deviation (inches)
Category-1 (No Damage)	96	47.54	10.96
Category-2 (Lateral Stem)	155	45.84	7.61
Category-3 (Terminal Bud)	69	31.75	6.31
Category-4 (Terminal bud & Lateral stem)	104	29.77	8.02

3.3.1. General linear model and PTAEDA 3 seedling height productions

Using the findings above, general linear models were used to analyze independent variables (field and wildlife browse damage category) for potential relationships with the dependent variable (mean ending stand height). The statistical output, listed in Table 3.10, indicated a significant interaction (F = 3.78) between independent variables (field * wildlife browse damage category) at the 0.01 alpha-level (P < 0.01).

Table 3.10. General linear model statistical output of between-subjects interaction between independent variables (field and damage category) on the dependent variable (mean seedling height)

Model	Degrees-of-freedom	Mean square	F- value	P-value
[a]Corrected model	15	1919.35	28.77	0.000
Field	3	113.16	1.70	0.167
Damage category	3	6748.78	101.164	0.000
Field * Damage Category	9	250.05	3.748	0.000

[a]$R^2 = 0.514$; Adjusted $R^2 = 0.496$

The data were split by the wildlife browse damage variable and a pair-wise comparison of field sublevel variables (AGL1; AGL2; AGL3; AGL4) and mean ending seedling height revealed an interaction between study site variable AGL1 and wildlife browse damage variables where the average height of seedlings in wildlife browse damage category-2 (46.17 inches) was statistically taller (P = 0.011) than the average height of undamaged seedlings in category-1 (39.90 inches). However, the output revealed no interaction between independent variables in field AGL2, AGL3, and AGL4.   Table 3.11 provides the mean ending height of seedlings by field and by wildlife browse damage category levels for all silvopasture sites on Redstone Arsenal.

Table 3.11. General liner model estimated marginal means and confidence intervals of the main effect interaction between independent variables (field * browse damage category) on dependent variable (mean seedling height) for all silvopasture sites on Redstone Arsenal.

Field	Wildlife Browse Damage Category (levels: 1 - 4)	Mean Seedling Height (inches)	Std. error	95% Confidence Interval	
				Lower bound	Upper bound
AGL1 (5.83 acres)	1 = No damage	39.895	2.109	35.749	44.041
	2 = Lateral stem	46.175	0.925	44.357	47.993
	3 = Terminal bud	32.087	2.583	27.009	37.164
	4 = Terminal bud and lateral stem	31.948	1.046	29.892	34.004
AGL2 (4.80 acres)	1 = No damage	47.732	1.155	45.462	50.003
	2 = Lateral stem	44.816	2.358	40.181	49.451
	3 = Terminal bud	30.874	1.467	27.990	33.758
	4 = Terminal bud and lateral stem	24.252	2.109	20.106	28.398
AGL3 (4.17 acres)	1 = No damage	50.287	1.741	46.864	53.710
	2 = Lateral stem	45.098	1.291	42.559	47.637
	3 = Terminal bud	30.874	1.826	29.402	36.583
	4 = Terminal bud and lateral stem	24.252	1.826	26.213	33.393
AGL4 (2.86 acres)	1 = No damage	50.287	2.723	47.187	57.891
	2 = Lateral stem	45.098	1.634	43.277	49.700
	3 = Terminal bud	32.993	2.888	25.917	37.270
	4 = Terminal bud and lateral stem	29.803	2.888	17.728	29.082

Although the model indicated an interaction between AGL1 and wildlife browse damage category, as shown in Table 3.11 the mean heights of seedlings in wildlife browse damage category-1 for study sites AGL2, AGL3 and AGL4 were statistically taller than that of seedlings in wildlife browse damage category-2. Table 3.12 and Figure 3.5 show the results comparisons between wildlife browse damage category levels and mean seedling height for all silvopasture sites on Redstone Arsenal.

Table – 3.12. Estimated marginal means from the linear model – effect of independent variable (field) on dependent variable (mean seedling height).

			95% Confidence Interval	
Independent Variable (Field)	Mean Seedling Height (inches)	Std. error	Lower bound	Upper bound
AGL1	37.526	0.904	35.749	39.303
AGL2	36.919	0.918	35.113	38.724
AGL3	39.545	0.843	37.888	41.202
AGL4	38.506	1.293	35.964	41.049
Independent Variable (Wildlife browse damage category)	Mean Seedling Height (inches)	Std. error	Lower bound	Upper bound
1 = No damage	47.613	1.007	45.634	49.593
2 = Lateral stem	45.644	0.820	44.033	47.256
3 = Terminal bud	31.887	1.132	29.662	34.112
4 = Terminal bud and lateral stem	27.352	1.037	25.313	29.391

As shown in table 3.12, in the marginal means estimated by the general linear model is contrasted to those for wildlife browse damage category, and when the data were split by field variables the statistical interaction between independent variables offered a different point of reference for interaction between field and browse damage variables. Table 3.13 provides the output of the general linear model that showing the statistics for main effects between the two independent variables (field and wildlife browse damage category) when the data were split by field variable. A pair-wise comparison between wildlife browse damage category levels and average stand height revealed that undamaged seedlings (wildlife browse damage category-1) and seedlings with lateral stem damage only (wildlife browse damage category-2) were not statistically different ($P = 0.767$) across all silvopasture study sites.

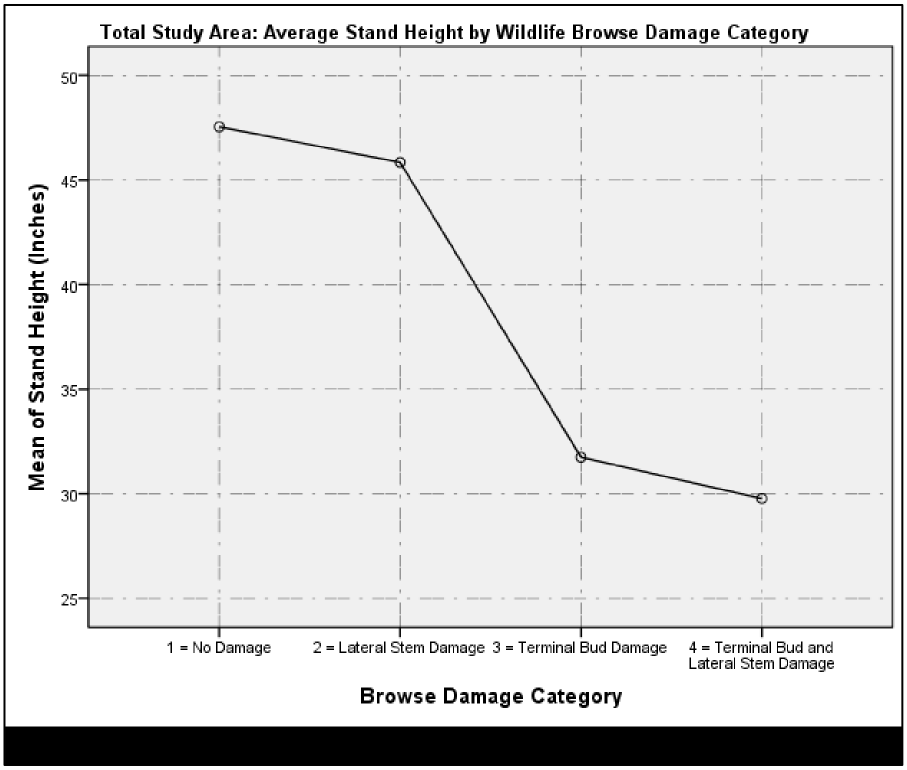

Figure 3.5. Mean seedling (N = 424) height by wildlife browse damage category for all silvopasture sites on Redstone Arsenal in November of 2011

Additionally, the statistical output indicated that the average height of both undamaged seedlings (wildlife browse damage category-1) and seedlings with lateral stem damage only (wildlife browse damage category-2) were both significantly taller ($P < 0.01$) than the mean height of seedlings with terminal bud damage (wildlife browse damage category-3) and seedlings with both terminal bud and lateral stem damage (wildlife browse damage category-4), which were not statistically different from each other ($P = 0.117$).

Table 3.13. Results of the pair-wise comparisons between wildlife browse damage category levels and mean seedling heights across all silvopasture sites on Redstone Arsenal in 2011.

Browse damage category	Browse damage category	Mean difference	Std. error	**P-value**	95% Confidence Interval Lower bound	95% Confidence Interval Upper bound
1= No damage	2 = Lateral stem	2.92	3.008	**0.767**	-4.94	10.77
	3 = Terminal bud	16.86	2.139	**0.000**	11.27	22.44
	4 = Terminal bud and lateral stem	23.48	2.754	**0.000**	16.29	30.67
2 = Lateral stem	1 = No damage	-2.92	3.008	**0.767**	-10.77	4.94
	3 = Terminal bud	13.94	3.181	**0.000**	5.64	22.25
	4 = Terminal bud and lateral stem	20.56	3.624	**0.000**	11.10	30.03
3 = Terminal bud	1 = No damage	-16.86	2.139	**0.000**	-22.44	-11.27
	2 = Lateral stem	-13.94	3.181	**0.000**	-22.25	-5.64
	4 = Terminal bud and lateral stem	6.62	2.943	**0.117**	-1.06	14.31
4 = Terminal bud and lateral stem	1 = No damage	-23.48	2.754	**0.000**	-30.67	-16.29
	2 = Lateral stem	-20.56	3.624	**0.000**	-30.03	-11.10
	3 = Terminal bud	-6.62	2.943	**0.117**	-14.31	1.06

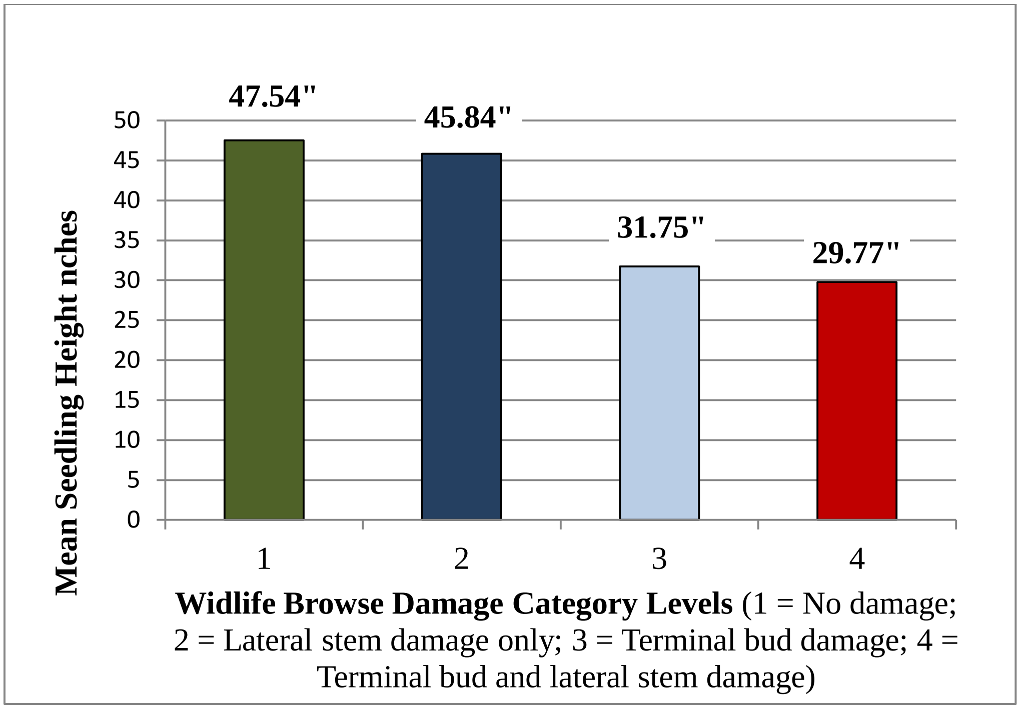

Figure 3.6. Results of the analysis between wildlife browse damage levels and mean seedling height in average stand height across each wildlife browse damage category levels across all silvopasture sites on Redstone Arsenal

Based on the mean heights of the four wildlife browse damage levels showing in Figure 3.6, PTAEDA 3 growth and yield software projected a range of 7to 8 feet as the average height of seedlings in wildlife browse damage category-1and browse damage category-2. When compared to the Hamilton (2008) recommendation of 5 to 6 feet and 7 feet in Pearson (1984), the projected range of 7 to 8 feet would satisfy minimum height recommendations by the end of the 3rd growing season in December of 2012. Alternatively, the projected average height of seedlings in browse damage category-3 and browse damage category-4 were in the height range of 4 to 6 feet which would meet the height requirement of 5 feet but not the height requirement of either 6 or 7 feet. Utilizing existing literature and the results of the PTAEDA 3 seedling height projections in characterizing the percentage of trees with terminal bud damage (category-3 = terminal bud damage; category-4 = terminal bud and lateral stem damage) to potentially be at risk of mortality due to cattle introduction; results are presented in Table 3.11.

Table 3.14. PTAEDA 3 projected loblolly average seedling height in December of 2012 for all four wildlife browse damage category level in comparison to the recommended minimum heights for cattle introduction to pine silvopastures on Redstone Arsenal in Alabama.

Seedling Mortality Category; (Number of Seedlings)	Mean Height of Loblolly Seedlings by Wildlife Browse Damage Category (Levels) in December of 2011	Projected Mean Height of Loblolly Seedlings by Wildlife Browse Damage Category (Levels) in December of 2012 when Cattle are Introduced	Minimum Seedling Heights for Cattle Introduction **(Pearson 1984; Hamilton 2008)**
Alive; (96)	(Category-1; 47.54 in.)	85 – 106 inches = 7 – 8 feet	5 feet = Pass 6 feet = Pass 7 feet = Pass
Alive; (155)	(Category-2; 45.84 in.)	86 – 101" inches = 7 – 8 feet	5 feet = Pass 6 feet = Pass 7 feet = Pass
Alive; (69)	(*Category-3; 31.75 in.)	53 – 67 inches = **4 – 6 feet (*At-Risk for cattle introduction*)**	5 feet = Pass 6 feet = ***Fail** 7 feet = ***Fail**
Alive; (104)	(*Category-4; 29.77 in.)	49 – 67 inches = 4 – 6 feet **(*At-Risk for cattle introduction*)**	5 feet = Pass 6 feet = ***Fail** 7 feet = ***Fail**

Based on the output from PTAEDA 3 growth simulations listed in Table 3.14, the projected average height of seedlings with terminal bud damage and terminal bud plus lateral stem damage (the seedlings in both category-3 and category-4) will not satisfy the minimum height recommendations for 6 to 7 feet (Pearson 1984; Hamilton 2008). Collectively, the total proportion of seedlings per acre represented by these two categories is 28% of seedlings per acre. The product of multiplying 28% of seedlings per acre by the 2012 seedling replacement value per acre resulted in the financial projection that a directly proportional 28% of 2012 seedling replacement value per acre ($/acre) was classified as being at-risk due to insufficient average height.

Figure 3.7 shows proportional representation of seedlings per acre grouped by mortality category in 2011 (alive; not-alive; missing). The 69% of seedlings "alive" in 2011 are subdivided by wildlife browse damage category levels (WBD Levels) with 41% of the orginial 350 trees per acre reflected in category levels 1&2, which not projected to be at-risk for cattle introduction in 2012 (refer back to Table 3.14) . However, the results of PTAEDA 3 loblolly growth simulations project the seedlings in wildlife browse damage category levels 3&4 (28%) to be at-risk for cattle introduction for all silvopasture sites on Redstone Arsenal in 2011. Even though the missing 14% of seedlings per acre and the 17% seedling mortality per acre are reflected in 2011 nominal values, the unit value is on a per acre basis, therefore the value of the other 69% of seedlings per acre were considered as 69% of the 2012 replacement value per acre and is both intrinsically linked to and directly based directly 2009 seedling establishment cost ($/acre).

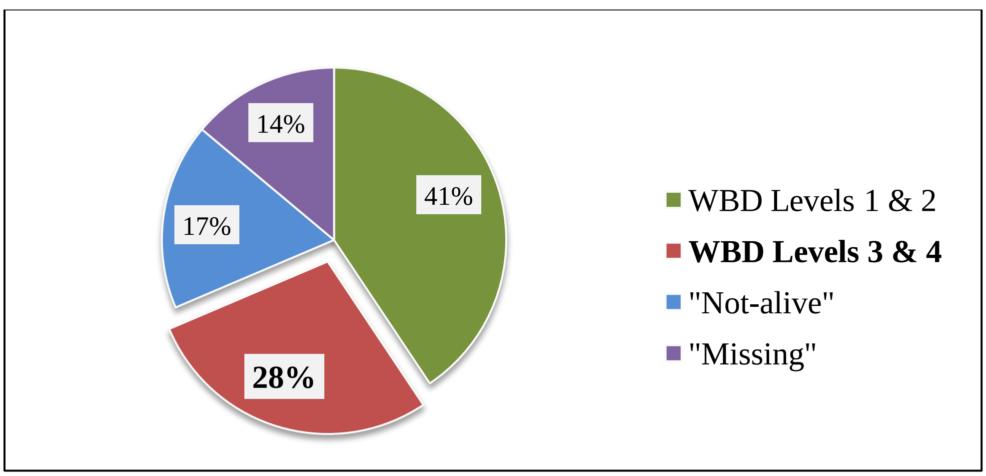

Figure 3.7. Proportional representation of establishment cost value per acre ($/acre) for all silvopasture sites on Redstone Arsenal in 2011.

3.3.2. Replacement cost approach and general discounting

Using the 2009 seedling establishment cost of $107/acre, the replacement cost approach and three interest rates, the results for the 2012 seedling replacement value ($/acre) were calculated as $117/acre, $127/acre, and $138/acre at 3%, 6%, and 9% interest rates respectively for all silvopasture sites on Redstone Arsenal and are displayed in Table 3.15. The results of discounting cattle lease revenue for one year, from 2013 to 2012, were $19/acre, $19/acre respectively. Following similar discounting procedure for hay revenue, the results were $58/acre, $57/acre, and $55/acre respectively and are summarized in Table 3.16. In Table 3.17, product of multiplying the 2012 seedling replacement value ($/acre) by the five different seedling mortality rates associated with the 28% of seedlings per acre that the PTAEDA 3 growth simulations projected to be at-risk for cattle introduction in 2012 ranged from $8/acre to $39/acre loss in seedling replacement value per acre. Table 3.18 provides an outline as to how individual 2012 values for seedlings, cattle, hay, and potential seedling damage costs were classified as a benefit or cost and incorporated in the net present value framework.

Table 3.15. 2012 replacement cost value per acre for 3-year old loblolly seedlings across all silvopasture sites on Redstone Arsenal.

	Interest Rates (%)		
Establishment and Replacement Value	3%	6%	9%
2009 Seedling Establishment Cost ($/acre)	$107/acre	$107/acre	$107/acre
Number of years used in Equation 1	3-years	3-years	3-years
2012 Seedling Replacement Value ($/acre)	$117/acre	$127/acre	$138/acre

Table 3.16. 2013 nominal values ($/acre) of individual cattle and hay components discounted to 2012 values ($/acre) for all silvopasture sites on Redstone Arsenal.

Discount Rate (%)	2013 Cattle Lease Value ($/acre)	**2012 Discounted Cattle Lease Value ($/acre)**	2013 Hay Production Value ($/acre)	**2012 Discounted Hay Production Value ($/acre)**
3%	$20/acre	$19/acre	$60/acre	$58/acre
6%	$20/acre	$19/acre	$60/acre	$57/acre
9%	$20/acre	$18/acre	$60/acre	$55/acre

Table 3.17. Potential loss of seedling value based on the 2012 replacement cost value for seedlings and the PTAEDA 3 projections for seedlings "at-risk" for cattle introduction to silvopastures at Redstone Arsenal in 2012.

2012 Replacement Cost Value Per Acre ($/acre)	Scenario B (one-quarter were lost)	Scenario C (one-half were lost)	Scenario D (three-quarters were lost)	Scenario E (all were lost)
$117/acre	($8/acre)	($16/acre)	($25/acre)	($33/acre)
$127/acre	($9/acre)	($18/acre)	($27/acre)	($36/acre)
$138/acre	($10/acre)	($19/acre)	($29/acre)	($39/acre)

Table 3.18. Net present value per acre (NPV/acre) of 2012 benefits/acre minus the 2012 costs/acre of management decisions regarding the introduction of cattle and potential trade-offs between the value of the tree component for all silvopasture sites on Redstone Arsenal

December 2012: Management Options and Damage Scenarios for Tree, Cattle , and Hay Production	NPV/acre = (∑PVB/acre – ∑PVC/acre) @ 3%; 6%; 9%;
Option 1. Postpone cattle assuming that all "at-risk" seedlings and associated seedling value/acre would be lost (** Hay would not be produced from silvopasture alleys in the absence of cattle introduction unless indicated**)	2012 NPV/acre = (28% of 2012 tree replacement value/acre) – (2012 cattle lease value/acre)
Option 2. Introduce Cattle (scenario A) : assuming no loss of "at-risk" seedlings	2012 NPV/acre = (2012 cattle lease value/acre)
*** scenario (2-B)**: assuming one-quarter of "at-risk" replacement value/acre was lost	2012 NPV/acre = (2012 cattle lease value/acre) – (7% of 2012 replacement value/acre)
*** scenario (2-C)**: assuming one-half of "at-risk" replacement value/acre was lost	2012 NPV/acre = 2012 cattle lease value/acre) – (14% of 2012 replacement value/acre)
*** scenario (2-D)**: assuming three-quarters of "at-risk" seedlings and associated seedling value was lost	2012 NPV/acre = (2012 cattle lease value/acre) – (21% of 2012 replacement value/acre)
*** scenario (2-E)**:introduce cattle assuming all "at-risk" seedlings and associated seedling value was lost	2012 NPV/acre = (2012 cattle lease value/acre) – (28% of 2012 replacement value/acre)
Option 3. Postpone cattle and produce hay: assuming all "at-risk" seedlings and associated replacement value/acre would be lost	2012 NPV/acre = (2012 hay value/acre + 28% of 2012 seedling replacement value/acre) – (2012 cattle lease value/acre)

3.3.3. Net present value (NPV/acre) of management options

The results of the net present value analyses are listed in Table 3.19, with the highest NPV/acre resulting from management option 3(postpone cattle and produce hay) and ranged from $72/acre to $76/acre. If hay production is not an option, then management option 1 (postpone cattle introduction) produced the next highest NPV/acre ranging from $14/acre to $21/acre, unless the management scenario-2A (cattle introduction and no loss of "at-risk" replacement value/acre) could be expected to occur. In this management scenario, postponing cattle produced the highest NPV/acre because the loss of one-quarter of at-risk seedling resulted in a lower NPV per acre.

In contrast to postponing cattle, if even one-quarter of the 28% of seedling value was expected to be lost, such as in management scenario 2-B then the NPV/acre declined to a range of $8/acre to $11/acre which was below the $14/acre to $21/acre that was calculated for management option 1 where cattle were introduction was completely postponed and the revenue/acre for the cattle leases ($18/acre to $19/acre) represented the opportunity cost of tree production. If cattle are introduced and no loss was expected then the NPV of $18 to $19/acre was the highest that could be expected. Finally, however, in management scenarios 2C – 2E, the NPV/acre varied widely based on the percentage of expected seedling loss and the interest rate used in the replacement cost calculations if approximately one-half of at-risk seedlings were lost due to cattle introduction, the NPV/acre declined from approximately $11/acre and turned negative where -$21/acre was the result from losing all at-risk seedling replacement value.

Table 3.19. Net present value per acre (NPV/acre) of management decisions regarding the introduction of cattle and potential trade-offs between the value of the tree and livestock components for all silvopasture sites on Redstone Arsenal in Alabama.

December 2012: Management Options and Damage Scenarios for Tree, Cattle , and Hay Production	Discount/Interest Rate %	NPV ($/acre)
Option 1. Postpone cattle assuming that all "at-risk" seedling replacement value/acre would be lost (** Hay would not be produced from silvopasture alleys in the absence of cattle introduction unless indicated**)	3%	$14
	6%	$17
	9%	$21
Option 2. Introduce Cattle (scenario A) : assuming no loss of "at-risk" seedlings	3%	$19
	6%	$19
	9%	$18
*** scenario (2-B)**: assuming one-quarter of "at-risk" replacement value/acre was lost when cattle are introduced	3%	$11
	6%	$10
	9%	$8
*** scenario (2-C)**: assuming one-half of "at-risk" replacement value/acre was lost when cattle are introduced	3%	$3
	6%	$1
	9%	$0
*** scenario (2-D)**: assuming three-quarters of "at-risk" seedlings and associated seedling value was lost when cattle are introduced	3%	**- $6**
	6%	**- $8**
	9%	**- $11**
*** scenario (2-E)**:introduce cattle assuming all "at-risk" seedlings and associated seedling value was lost when cattle are introduced	3%	**- $14**
	6%	**- $17**
	9%	**- $21**
Option 3. Postpone cattle and produce hay: assuming all "at-risk" seedlings and associated replacement value/acre would be lost when cattle are introduced	3%	$72
	6%	$74
	9%	$76

3.4. DISCUSSION

The purpose of this research was to examine three distinct but related aspects of wildlife browse damage to southern yellow pine establishment and growth in silvopasture systems that were established on Redstone Arsenal (RSA) in December of 2009. The following year, in December of 2010, RSA foresters reported wildlife browse damage to some of the 1-year old loblolly pine seedlings. According to RSA, the situation caused uncertainty among managers regarding the possibility seedling mortality and reduction in value of the tree component. Furthermore, the damaged seedlings generated questions that pertained to stunted seedling growth and the possibility further tree damages if cattle were introduced too soon.

The potential impact of wildlife browse damage to silvopasture functionality and value were important to RSA because their stated objectives were to systematically enhance the ecological and economic integrity of lands owned and operated by the United States Army by integrating the production of trees, forage, and cattle into a sustainable system on the same land-unit. The main objectives of this study were to assess the 1-year old loblolly pine seedlings in four silvopastures for wildlife browse damage, characterize browse damage variables, measure seedling heights and mortality, and analyze these data to uncover previously unstudied relationships.

This study hypothesized that the severity (lateral stem vs. terminal bud), repetition (single damage event vs. multiple), and timing (winter vs. spring) of wildlife browse damage would produce differential seedling survival and height by the end of the second growing-season. Furthermore, based on the established literature relative to the management of timber and cattle in a silvopasture system, seedling mortality caused by wildlife browse damage could potentially be high enough such that RSA foresters would need to consider postponing cattle to completely replant the loblolly pine seedlings, or the growth rate of seedlings reduced to the point where a significant proportion of seedlings/value per acre ($/acre) could be at risk of loss due to cattle damage and may exceed value gained by revenue from cattle introduction.

3.4.1. Biological interactions

The results of this study suggest, specifically, that there is a statistically significant inverse relationship between average stand height after the 2^{nd} growing-season and variables expressing the severity of wildlife browse damage to seedlings in the 1^{st} year (variables expressed as wildlife browse damage ≥ level 3 = terminal bud damage). Moreover, the projected results for 3^{rd}-year average seedling heights suggest, specifically, that severe wildlife browse damage (≥ level 3 = terminal bud damage or greater) to seedlings in the 1^{st} year could increase the potential for cattle related tree damages if cattle are introduced to the silvopastures on Redstone Arsenal in Madison County, Alabama. The results of this study mean that the biological impact of wildlife damage to individual silvopasture components, the functionality and establishment of a complete system, and the economic trade-off among component values or between values associated with alternative management options depend on the characteristics and extent wildlife browse damage during the first year, seedling mortality and growth response over the first, second, and third growing seasons, and the objectives of landowners and values they assign to each component and economic trade-offs resulting from choice among multiple management scenarios.

Second, this study did not observe significant browse damage to occur during spring, summer, or autumn of 2011; suggesting that the damage was present before this study began and that the mere presence of silvopasture may not influence the timing of seedling browse damage.

It should be noted that the literature clearly states that pine are not preferred food items however this interaction was not well understood for landscapes under silvopasture management practices.

Third, the importance of the timing of damage may be important because browse damage was observed on more than 80% of all seedlings in this study. If the timing of damage is concentrated over the winter months, seedling protection efforts may be more effective and cost efficient due to accurate knowledge of when the protection is needed. Please note however that this study was limited to observations in the 2nd growing season only, therefore the true timing of the observed browse damage is still unknown.

Fourth, this study assumed browse damage to be evenly distributed across all seedlings in all study sites. While seedlings could be assigned spatial coordinates, their representation and analysis in fields of such limited size was not practical and when combined with other confounding variables such as edge-perimeter ratios, wildlife activity at Redstone Arsenal and the potential influences of man-made infrastructure on wildlife foraging behavior was beyond the scope this study. Fifth, the true nature of "MISSING" seedlings was unknown. The knowledge of whether or not those seedlings were planted or whether they had been planted and died within the 1st year would have provided more data for analysis. For example, the true nature of the "missing" seedlings could have provided data that affected the overall mortality rate and stand seedling value/acre. As a result this unknown however all of the "Missing" seedling designations their value was not represented in economic analyses.

Sixth, a wide range of variables associated with individual site conditions such as damage from other organisms and human activities, such as mowing (or predator drones), may or may not have had a unique impact on the observations and data collection. Other such data were noted by this study, however time and resource limitations did not allow for the systematic and sufficient collection of such data to be formally incorporated into analysis procedures. Future research might incorporate and analyze detailed variables which may impact and interact with seedling growth in addition to potential wildlife browse damage including, damage from insects and other pests, competition from vegetation within seedling rows, human use, road proximity, proximity of man-made structures, hunting pressure, seedling genotype, and planting method.

Finally, the impact of wildlife browse damage on seedling growth was projected to influence the timing and initiation of cattle-grazing contracts after the 3rd growing season. It is important to note however that the probability of cattle damage as it relates to seedling height is not well understood and that the literature provides contrasted recommendations for the minimum height of seedlings (Pearson 1984; Hamilton 2008). For example, multiple species of southern yellow pine (loblolly, shortleaf, and longleaf) are considered to be suitable for use in silvopasture, of which each may have a differing growth rate that can vary widely, based on many variables.

The Hamilton (2008) recommendation of 5 to 6 feet being required for livestock introduction in a southern pine silvopasture does not specify which animal species (cattle; sheep; goats) can be introduced at 5 feet and which species may be introduced at 6 feet. In general the recommendation does not seem to account for differing body mass, height and behaviors between cattle, sheep and goats that in turn may require differing minimum tree heights based on the species of pine being utilized. The southeastern U.S. describes a geographically, climatically and biotically diverse land area in which deer populations have been increasing at a relatively rapid rate over the last 30 years and the potential for damage in silvopastures and agroforestry systems as a whole is currently not well understood.

3.4.2. Economics of management options

The economic results for Redstone Arsenal suggest that postponing cattle for an additional year and producing hay from the alleyways in all silvopasture sites would yield a higher NPV/acre than would other management options. If hay production is not an option for RSA managers in 2013, then postponement of cattle alone was the most efficient choice because the loss of even one-quarter of "at-risk" seedlings reduced the NPV below that of postponing cattle introduction. Any reader should also be aware that the $20/acre generated by the cattle grazing-leases on Redstone Arsenal may or may not vary widely for any individual or organization. It is also important to note that any biological or economic management decision may follow similar methods as outlined in this study but must be based on individual and site specific details and relationships. The economic projections shown here are representative of this particular scenario at this point in time.

However, a silvopasture's 3-year old loblolly pine component was assigned a relative value based on the replacement cost approach that involved compounding the establishment cost at conservatively selected interest rates. This was done because the investment principal/cost to establish loblolly pine as the tree component of a southern silvopasture is a recoverable value through timber sales, but in the interim is a capital asset employed to reduce both fixed and variable costs of cattle production. The methods outlined by this study may be appropriate for evaluating similar silvopastures, with similar components and site conditions in Alabama.

This is important for many reasons, none of which is because discounting future timber revenue is somehow wrong, but because of the straightforward applicability of the replacement cost approach for Alabama's farmers and landowners. The variability among these potential silvopasture adopters suggests that the interactions and trade-offs between relative timber and livestock values may be more readily assessed by a larger range of Alabama's residents whether he or she needs to value some form of damage to pre-merchantable timber, is considering the expansion of current operations, transitioning from traditional agriculture and forestry to silvopasture, or taking out a loan in order to establish a first generation farm.

Further research related to tax accounting methods and the relative impacts on financial statements may be useful to those same groups of stakeholders who seek incentives, must evaluate the farms net income, seek credit and equity related investments in their farm business or silvopasture production cooperative. Research suggests that wildlife browse damage can negatively influence silvopasture components, influences on the timing of cash-flows, and thereby its value. Things which influence or can influence cash-flows are generally important to a wide range of people and businesses (Godsey 2007; Hamilton 2008; Godsey et al. 2009).

3.5. MANAGEMENT IMPLICATIONS

Based on the results of this study, management and personnel at Redstone Arsenal should be advised of the potential impact of wildlife browse damage on the timing of livestock introduction. The results of this study suggest that ground-truthing of study sites by Redstone personnel may be warranted near the end of the 2012 growing season in order to evaluate the accuracy of growth projections presented in this study. Second, similar to Godsey and Dwyer (2008) the difference between the NPV of a silvopasture without damage and the NPV of a silvopasture with damage respectively could be considered in future studies to represent a landowner's Willingness-to-Pay (WTP) for seedling protection in year 0 at the time of establishment (Godsey and Dwyer 2008; Ittleson 2009; Zhang and Pearse 2011). By using the methods outlined in this study, after stakeholders have valued the potential damage loss, they can use that value as a budget tool or guide while comparatively shopping for various protection mechanisms, devices, or services.

Additionally, the incorporation of hunting leases, special tax incentives and payments from cost-share programs such as the Conservation Reserve Program (CRP) and the Wildlife Incentive Program (WHIP) make the practice of silvopasture a financially attractive land management option (Husak and Grado 2001; Husak and Grado 2002; Rollins et al. 2004; Godsey 2007; Lemus 2009). However, the work done by Grado et al. (2001), Husak and Grado (2002) and Godsey et al. (2009) suggest that tree/timber component of southern yellow pine silvopastures can produce a combination of financial benefits not just from timber revenue but from related sources that include 1) increased cattle performance due to tree shade which translated into live weight gains and therefore higher average revenue per cattle unit, 2) reduced fixed and variable cash and non-cash costs for supplemental feed, water, and other animal maintenance, and 3) improved cash-flows from hunting leases because as the tree component matures so should vertical and horizontal biodiversity and field-edge/perimeter ratios which translates into enhanced resource quality, diversity, availability, and juxtaposition of wildlife habitat components. This has the potential to translate into benefits on other southern pine silvopastures therefore the ability of wildlife and cattle to severely damage young pine seedlings may warrant further investigation in relation to livestock introduction and the average heights at which some of the more common southern yellow pine species can withstand introduction without severe damage and how those variables change based on the species of livestock being introduced.

Furthermore, if wildlife browse damage to seedlings in a recently established silvopasture system can be expected to occur primarily during the nutritionally stressed winter months then the incorporation of hunting leases may provide financial benefits in addition to the revenue of the hunting lease which includes the preservation the existing tree component value and future appreciation due to biological growth, and may help to minimize costs associated with a need for timber protection. The aforementioned variables may be important for a diversity of stakeholders but for small-scale farmers and landowners, short-term cash-flows are generally a very important consideration. However, the literature provides few examples for incorporating wildlife damage into accepted valuation methods.

Benjamin Graham summarized the management implications well in stating: "It has been an old and sound principle that those who cannot afford to take risks should be content with a relatively low return on their invested funds. From this there has developed the general notion that the rate of return which the investor should aim for is more or less proportionate to the degree of risk he is ready to run. Our view is different. The rate of return sought should be dependent, rather, on the amount of intelligent effort that the investor is willing and able to bring to bear on his task. The minimum return goes to our passive investor, who wants both safety of principal and freedom from concern. An investment operation is one which, upon thorough analysis, offers safety of principal and an acceptable return. Operations not meeting this requirement are speculative (Graham and Dodd 1934; Graham 1949)."

Management implications for the enterprising investor and manager of silvopasture operations: research suggests that a silvopasture system can offer both safety of an investments principal and an acceptable rate of return. However, silvopasture is not a plant it and leave it forestry operation. Management intensity and component ratios vary based on a variety of factors including landowner objectives, region, climate, and component species. When those factors are combined with others including the financial condition and tax classification of the landowner or farm business, local market conditions, and changing consumer preference, thorough budget analysis and planning for the silvopasture are important and may impact the return on investment. “The underlying principles of sound investment should not alter from decade to decade, but the application of these principles must be adapted to significant changes in the financial mechanisms, climate, and broader environment (Graham 1949).”

Silvopastures alter habitat components, can attract wildlife, and create the potential for human-wildlife conflict (Grado et al. 2001; Conover 2002; Sharrow and Fletcher 2003). Because the potential for negative interactions and associated costs are relatively unknown and have limited data available, it is important for landowners and land managers to do the following: 1) Record observations of increasing use by wildlife and potential damages caused to trees or to livestock. 2) Keep detailed records of planting methods, costs, and tree height at the time of livestock introduction. 3) Record annual rainfall and seedling height measurements, insects, extreme climatic events, surrounding habitat conditions, livestock damages, timber growth, tree canopy cover, average animal/breed weights, average market price received, average costs of fertilizer, supplemental feed and any other performance indicator or metric which you believe would help you understand were another person communicating to you. These data would be of value, both at present and in the future, to a diverse range of landowners, farmers, and investors when evaluating the costs and benefits of integrating trees, forage, and livestock on the same land-unit.

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Appendix 1: Location of Redstone Arsenal in Madison County, Alabama in relation to Auburn University which is located in Lee County, Alabama.

Appendix 2. List of woody & non-woody plant species that were identified in habitat surrounding all study sites on Redstone Arsenal in Madison County, Alabama.

Scientific name	Common Name
Acer rubrum	Red maple
Andropogon spp.	Broomsedge
Carya ovalis	Red hickory
Carya ovata	Shagbark hickory
Cercis canadensis	Eastern redbud
Cornus florida	Flowering dogwood
Diospyros virginiana	Common persimmon
Fagus grandifolia	American beech
Gleditsia triacanthos	Honey locust
Liquidambar styraciflua	Sweetgum
Liriodendron tulipifera	Tulip poplar
Morus rubra	Red mullberry
Pinus echinata	Short leaf pine
Pinus taeda	Loblolly pine
Prunus serotina	Black cherry
Quercus falcata	Southern red oak
Quercus michauxii	Swamp chestnut oak
Quercus nigra	Water oak
Quercus pagoda	Cherrybark oak
Quercus rubra	Northern red oak
Sassafras albidum	Sassafras
Setaria spp.	Foxtail
Smilax spp.	Green-briar
Trifolium spp.	Clover
Vicia spp.	Vetch

Appendix 3: Location of study sites (AGL1; AGL2; AGL3; AGL4) on Redstone Arsenal in Madison County, Alabama in 2011.