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Silvopasture in the Northeastern United States

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SILVOPASTURE IN THE NORTHEASTERN UNITED STATES

BY

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DISSERTATION

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SILVOPASTURE IN THE NORTHEASTERN UNITED STATES

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University of New Hampshire, May, 2015

Silvopasture, the sustainable integration of livestock and trees on the same unit of land, may have the potential to contribute to agricultural productivity in the Northeastern United States and concurrently encourage the ecosystems services which trees provide. Extremely little is known regarding the ecological characteristics of silvopastures being utilized, their social and economic drivers, or their agricultural productivity. Silvopasture characteristics, management, and reasons for use were documented through a purposeful sample of silvopasture practitioners in New York and New England. Results document the functional role of silvopastures on regional farms. This research also investigated the ecological and production dynamics of silvopastures in the Northeastern United States, their management, and the reasons for their use. Forest conversion to silvopasture, open pasture, and heavily thinned forests were utilized to investigate the ecological and production dynamics during the establishment phase of forest conversion to pasture. Results suggest the potential for silvopasture as a competitive management option for forestland. This dissertation establishes a baseline for future investigations into the management of silvopastures in the Northeastern United States.

INTRODUCTION: SILVOPASTURE, A NEW OPPORTUNITY FOR THE NORTHEASTERN UNITED STATES

ABSTRACT

Due to the historically unsustainable nature of pastured woodlands occurring in the Northeastern United States, little mention of silvopasture in the region, and forester bias against livestock, a confusion exists between pasturing woodlands and silvopasturing. The intent of this document is to make a distinction between pastured woodlands and silvopasture in the Northeastern United States, while arguing for an advancement of silvopasture as a regional farming system. Two important distinctions between silvopastures and pastured woodlands are 1) that management of silvopastures maintains a forage and root layer which stabilizes soil and minimizes compaction, and 2) that trees are actively cultivated in silvopasture systems. Conversion of existing forests to silvopastures may be an effective way of expanding agricultural land in the Northeastern United States and there is a great deal of interest among farmers and some foresters related to the potential use of the practice. There is currently a dearth of information to rely on for informed management of Northeastern silvopastures. A serious effort needs to be made by researchers and extension professionals to develop best management practices for silvopasture if it’s going to displace pastured woodlands on regional farms. There is a timely need for applied research and education related to silvopasture management in the Northeastern United States.

INTRODUCTION

The longstanding and environmentally damaging practice of unmanaged pastured woodlands remains widespread in the Northeastern United States. In 2012, pastured woodlands accounted for 107,180 hectares (264,846 acres) of pastureland in New York and New England (National Agricultural Statistics Service, 2012). The management of these pastured woodlands was not addressed as part of the farm census, begging the question ‘Are the pastured woodlands of the Northeastern United States sustainably managed?’ Researchers in the Midwestern United States found that livestock are being pastured on 1/3 of farm woodlots in their region without the use of silvopasture (Garrett et al., 2004).

TABLE 1: Distribution of woodland pasture in New York and New England. Of total pastureland in the region, 1 in 6 hectares (17%) is woodland pasture. In the New England states the proportion of woodland pasture to total pasture area is over 1 in 5 (22%). These data were sourced from the Census of Agriculture but the management of these pastures was not addressed (National Agricultural Statistics Service, 2012).

State	*Land in Pasture (Hectares)*	*Woodland Pasture (Hectares)*	*Number of Farms Using Woodland Pasture*	*% of Total Pasture Acreage that is Woodland Pasture*
CT	29,157	8,531	1,056	29%
MA	34,721	7,218	1,093	21%
ME	48,170	10,969	1,103	23%
NH	18,804	5,037	706	27%
NY	398,985	59,487	5,286	15%
RI	4,088	923	198	23%
VT	78,947	15,014	1,184	19%
Region	612,873	107,180	10,626	17%

The practice of pastured woodlands has been occurring in the Northeast since colonization by Europeans (Russell, 1976) and it still occurs on 10,626 regional farms while accounting for 17% of regional pasture land (Table 1). In the New England states the ratio of woodland pastureland to total pastureland is 1:5, being that 22% of pastureland in the region is woodland pasture (Table 1). Extensive outreach work has been conducted in the region on appropriate management of open pastures through managed intensive grazing. Yet, 17% of the regional pastureland that is woodland has been ignored in terms of best management practices. The lack of management recommendations for wooded pastures in the region suggests that the vast majority of these woodlands may not be appropriately managed for livestock or trees. Foresters in the United States have long been taught that livestock and trees do not, and should not, be integrated. Pastured woodlands is a broad term which can apply to any wooded area experiencing livestock inclusion, regardless of management or objectives. However, the practice of silvopasture is defined as the sustainable and productive integration of both livestock and trees on the same unit of land. Work from the Midwest has documented conflict between foresters (who were against) and conservationist professionals (who were for) regarding forest conversion to silvopasture (Arbuckle, 2009).

Due to the historically unsustainable nature of pastured woodlands occurring in the Northeastern United States, little mention of silvopasture in the region, and forester bias against livestock, a confusion exists between pasturing woodlands and silvopasturing. The intent of this introduction is to make a distinction between pasturing woodlands and silvopasture in the Northeastern United States, while arguing for an advancement of silvopasture as a regional farming system.

SILVOPASTURE VERSES PASTURED WOODLANDS

Although silvopasture is the most common agroforestry practice utilized in North America (Udawatta and Jose, 2012), it is not likely that silvopasture makes up a large component of the pastured woodland in the Northeastern US. In a review of North American silvopasture systems, practices in the Western, Southern, and Midwestern regions of the continent were documented but practices in the Northeastern portions went unmentioned; probably due to the historic rarity of intentional silvopasture systems in this region (Clason and Sharrow, 2000).

Silvopastures are managed agricultural systems and must be carefully planned to maximize efficiency while minimizing detrimental ecological impacts (Chedzoy and Smallidge, 2011b). An argument can be made that livestock are inherently detrimental to trees. However, the same argument can be made that livestock are inherently detrimental to forage. The factor that is too often ignored in the argument against incorporating livestock with trees is management. The historic problems of pastured woodlands are not inherent to silvopasture, but they are inherent to continuous grazing of livestock with little management. Regardless of trees in a system, continuous grazing of livestock in an area will lead to tree or forage mortality and soil degradation. In silvopasture, grazing and recovery periods can be managed using modern technologies, such as portable electric fencing systems, enabling farmers to reduce the impact livestock have on any pasture system (Chedzoy and Smallidge, 2011b).

Two important distinctions between silvopastures and pastured woodlands are 1) that management of silvopastures maintains a forage and root layer which stabilizes soil and minimizes compaction, and 2) that trees are actively cultivated in silvopasture systems. The term pastured woodlands was specifically chosen in this paper instead of woodland grazing because woodland grazing misleads one to assume that there is forage available to graze. Image 1 provides an example of a pastured woodland in New York showing severe soil degradation and tree mortality. Image 2 provides an example of a silvopasture in New York as a contrast to the unsustainable pastured woodland seen in Image 1.

Additionally, a distinction between silvopasture and simply using livestock for woody vegetation management needs to be made. Vegetation management may be a component of silvopasture establishment, but the practice of solely using livestock to control woody vegetation is not silvopasture when intentional tree production is missing. While vegetation management using livestock may be a viable practice, little is known regarding the nutritional value or toxicity of common browse species or unwanted woody plants in the Northeastern United States. Filling this gap in knowledge would benefit both silvopasture and the practice of using livestock as a form of vegetation management.

IMAGE 1: Highly degraded pastured woodland on a farm in New York. This pasture is being continuously grazed by pigs; note the lack of a forage layer. Tree health and conservation is seriously threatened in this system because of extensive tree root exposure, soil compaction, and risk of soil loss. This is NOT a form of silvopasture.

WHY SILVOPASTURE IS APPROPRIATE FOR THE NORTHEASTERN UNITED STATES

There are both conservation benefits and agricultural benefits to silvopasture systems. Documented conservation benefits of silvopasture include incentives to manage farm woodlands, vegetation management of undesirable species, increased carbon storage, increased fertility of formerly degraded ecosystems, and landscape aesthetics (Chedzoy and Smallidge, 2011b; Clason and Sharrow, 2000; Garrett et al., 2004; Howlett et al., 2011b). For the farmer silvopasture provides reduced climate stress on livestock, increases in livestock weight gain, reduced calving difficulty, high quality forage production, summer slump forage availability, and multiple sources of economic revenue (Chedzoy and Smallidge, 2011b; Clason and Sharrow, 2000; Garrett et al., 2004; Kallenbach et al., 2009; McDaniel and Roark, 1956). A few studies have investigated the effects of silvopastures specific to forest ecosystems, and the results show the potential for silvopastures to contribute to forest productivity and ecosystem services (Garrett et al., 2004; Walter et al., 2007).

Much of the Northeast is covered in maturing forests due to agricultural land abandonment over the last 200 years. Conversion of existing forests to silvopastures may be an effective way of expanding agricultural land in the Northeastern United States while concurrently freeing up tillable cropland that is currently pastured. While conversion of both hardwood and softwood forests to silvopastures holds potential, the high timber value of the region’s hardwoods makes hardwood silvopasture a logical target for maximizing revenues. Two studies in the United States have addressed hardwood conversion to silvopasture. One, in West Virginia, compared forage production and soil chemistry in a thinned hardwood forest silvopasture to a decades old and established pasture (Feldhake et al., 2010). The other, from Missouri, provides a review of hardwood forest conversions to silvopasture (Garrett et al., 2004).

Both studies suggested that forest conversion to silvopasture is a viable practice in terms of agricultural productivity and ecosystem health. Planting trees in current pastures also holds potential for the expansion of silvopasture in the Northeast. Planting would be especially suitable to pastures in need of soil stabilization and areas where conservation incentives aim to deter periodic tilling.

IMAGE 2: Silvopasture in New York being grazed in its second year after establishment from a hardwood forest. Unlike pastured woodlands, this system has a diversity of forage in the understory and no bare soil exposure exists. Residual trees were favored by species and stem quality for the purpose of producing sawlogs. Short periods (1-2 days) of grazing are followed by long periods (>30 days) of rest to encourage forage and soil health.

In spite of limited publications addressing the details of silvopasture in the Northeastern United States, there is a great deal of interest among farmers and foresters related to the potential use of the practice in the region. This interest is evidenced by published work calling for adoption of silvopasture by farmers in the Northeast (Carroll, 2011; Chedzoy and Smallidge, 2011b); the Northeastern Silvopasture Conferences hosted by Cornell Cooperative Extension in 2011 and 2014; more than a dozen silvopasture educational field days held across the region between 2012 and 2015, and numerous presentations on silvopasture at professional farming and forestry meetings in the region (Chedzoy and Smallidge, 2011a). It is critical that researchers and outreach professionals take steps to maximize the viability of these systems through education and scientific inquiry as a response to increasing regional interest. Failure to do so will likely result in a greater confusion between pastured woodlands and the sustainable practice of silvopasture, as regional expertise of how to appropriately manage integrated tree and livestock systems is not currently widespread.

EUROPEAN CONSIDERATIONS

Global examples of silvopastoral practices are a testament to the viability of silvopasture. Numerous silvopasture systems have been sustained in Europe for hundreds of years and many of these are still widespread (Rigueiro-Rodriguez et al., 2009). These include 400 year old sessile oak (*Quercus petraea* Liebl.) plantation systems in Slovenia, seasonal silvopastures in the Alps, and numerous oak (*Quercus* spp) or pine (*Pinus* spp) systems integrated with cattle, swine, sheep, or goat production across the continent (Rigueiro-Rodriguez et al., 2009).

European silvopasture practices perhaps provide the most relevant examples for conceptualizing the potential for silvopasture utilization in the Northeastern United States. Europe is not only densely populated, but Northern and Central Europe share a similar temperate climate to that of the Northeastern United States. Additionally, the species composition of forests and pastures in Europe are similar to those found in North America. While the forests contain different species of trees, the genera are similar due to biogeographical history. Commonly managed pasture forages in the Northeastern US are primarily European in origin, with the exception of certain bluegrasses (*Poa* spp.) and bentgrasses (*Agrostis* spp.) (Barnes et al., 2003). Contributing to the similarities between the regions, the majority of all livestock raised in the Northeastern United States are, or have, origins with European breeds.

IMAGE 3: Olive orchard silvopasture in the Campania region of Italy. This >100 year old orchard demonstrates the long-term production potential of silvopasture orchards. Olive trees require a different climate than that found in the Northeastern United States, but similar silvopasture systems could be developed using fruit and nut trees hardy to cooler climates.

Fruit tree silvopastures have existed in Europe for centuries and provide an excellent comparison of what could be accomplished with silvopastures in the Northeastern United States. Germany historically had what were termed the “central European savannas”, areas of traditional orchards with incorporated livestock grazing (Rigueiro-Rodriguez et al., 2009). Two notable systems are the *pre-verger* systems in France and the *Streuobst* systems in central Europe. In the French system fruit trees are planted at low densities in croplands. Crops are grown between young fruit trees but as the trees mature, forages are established. Mature orchards are then grazed with livestock in a true silvopasture setting (Rigueiro-Rodriguez et al., 2009). In central Europe the *Streuobst* system consists of grazing and croplands with integrated fruit trees irregularly dispersed throughout (Rigueiro-Rodriguez et al., 2009). The density of fruit trees in these systems is typically between 20 and 100 trees per hectare (8-40 trees per acre) (Rigueiro-Rodriguez et al., 2009). In the Netherlands tall fruit trees pruned high have been traditionally incorporated with sheep and cattle grazing at a density of 50-150 trees per hectare (20-61 trees per acre) (Rigueiro-Rodriguez et al., 2009). Cattle and sheep are used to reduce the height of understory plants and in some cases pigs are incorporated to consume dropped fruit such as plums (Rigueiro-Rodriguez et al., 2009). Image 3 is an example of a more than century old olive (*Olea* spp.) orchard silvopasture in Italy, demonstrating the long-term production potential of silvopasture orchards.

The centuries old *dehesas* systems in Spain also provide a useful example for what could be developed as silvopastures in the Northeastern United States. These systems incorporate trees with livestock grazing on lands not suitable for tillage (Olea and San Miguel-Ayanz, 2006). Many of these systems incorporate cork-bark oak trees with sheep or cattle grazing (Rigueiro-Rodriguez et al., 2009). *Dehesas* are primarily derived from converted hardwood forests and, due to seasonal droughts, trees are actually viewed as mechanisms which encourage grass production through alteration of microclimate (Moreno and Pulido, 2009). In Spain, *dehesas* are considered a soil and ecosystem conservation practice (Olea and San Miguel-Ayanz, 2006).

Trees can be both planted and occur naturally, but typically all branches are maintained above browse height and products from the *dehesas* system other than livestock and cork include acorns and fuelwood (Olea and San Miguel-Ayanz, 2006). Written evidence of *dehesas* systems dates back to 924 AD, strong evidence toward the long-term sustainability of silvopasture systems (Olea and San Miguel-Ayanz, 2006). Currently these multipurpose open woodlands cover 3.1 million hectares of the continent (Moreno and Pulido, 2009).

The use of acorns and chestnuts as fodder crops has been documented in *dehesas* and other silvopasture systems in Europe (Olea and San Miguel-Ayanz, 2006; Rigueiro-Rodriguez et al., 2009). Systems that incorporate oak and chestnut trees occur across Europe and are some of the most important silvopasture systems for all types of livestock, for example, in the southern Alps sweet chestnuts cover more than 5 million acres (Rigueiro-Rodriguez et al., 2009). The leaves, buds, and nuts of these trees are utilized by livestock in varying locales and seasonal dates. Many of these systems contain the well-spaced and high crown structure of orchards while others are forestland where livestock are periodically grazed to collect mast (Rigueiro-Rodriguez et al., 2009). Pannage is a historic term for keeping livestock in woodlands to consume mast; this was also known as acorning. This practice was occurring in oak forests in Hungary in the 1300's and continued for centuries, but in 1769 goat grazing was prohibited due to forest regeneration concerns, yet cattle were still allowed (Rigueiro-Rodriguez et al., 2009). While these European systems are dynamic and adapted to unique cultural, biophysical, and economic conditions; they represent starting points for silvopasture advancement in the Northeastern United States.

FURTHER CONSIDERATIONS FOR SILVOPASTURE ADOPTION IN THE REGION

Current and proposed policies provide barriers for silvopasture adoption in the Northeastern United States. At a national scale, the USDA National Organic Program restricts the incorporation of raw manure into orchards within 90 days of harvest of produce (United States Department of Agriculture, 2015). This means that livestock grazing within orchards must not occur within 90 days prior to harvest of produce on certified organic farms. This limits the ability of organic farmers to utilize livestock for grass management in orchard silvopastures.

Local policy considerations regarding silvopasture include current use tax policies and cost sharing conservation programs. In most Northeastern states, current use tax policies provide savings for farmers practicing both sustainable and unsustainable grazing practices. Some states actively discourage the use of pastured woodlands. The following quote is part of a suggested response developed by Vermont's current use tax program for state officials who are dealing with forestland misuse on private lands (DFPR, 2010):

> It is the policy of the Department of Forests, Parks and Recreation to discourage the pasturing of animals in lands enrolled in the Forest Land category. We feel that it is best that animals not be pastured in woodlands due to the deleterious effect that they may have on trees, e.g. soil compaction, root collar destruction leading to pathogenic entry, increasing erosion, etc. Besides, the grass under the forest canopy generally isn't the best. Better to use the woods to grow timber and the fields to grow grass.

In short, this policy suggests that while pasturing livestock in woodlands is allowed in the current use tax program, the practice is discouraged regardless of management strategy. This policy also makes broad statements regarding the integration of livestock and trees which have been proven wrong in silvopasture systems around the world, especially related to forage quality and soil degradation when compared to open fields (Ladyman et al., 2003; Lin et al., 2001; Nair, 2011; Nair et al., 2007a; Nair et al., 2007b; Staley et al., 2008).

Cost sharing programs for silvopasture are uncommon in the Northeastern United States. Currently, only Massachusetts has a policy through NRCS for silvopasture practices (NRCS, 2012). How silvopasture compares as a conservation mechanism likely depends on what it is being compared to. When compared to open pastures or pastured woodlands, silvopasture holds a lot of potential as a conservation mechanism, especially in relation to carbon storage (Alavalapati et al., 2004; Howlett et al., 2011b; Udawatta and Jose, 2012).

Regional initiatives to increase the water quality of rivers and lakes through reduction of farm nutrient run-off should consider incentivizing silvopasture practices. In other regions of the United States, silvopasture has been found to reduce nutrient leaching from agricultural practices through soil stabilization, uptake by forages and trees, and nutrient uptake by tree roots in deep soil horizons (Nair et al., 2007a; Nyakatawa et al., 2012; Udawatta and Jose, 2012). Silvopasture also discourages the tillage of agricultural lands because tree roots inhibit the use of tillage equipment. From a forest health perspective, the adoption of silvopasture provides an incentive to manage invasive understory plants. There is also potential to use silvopasture as a periodic silvicultural treatment prior to a forest regeneration period. In many parts of the region non-management of forests has led to poor tree regeneration due to wildlife browse and understory of invasive alien shrubs. Managed grazing through silvopasture may act as a preparation tool to reduce invasive plant competition prior to livestock exclusion and the implementation of a forest regeneration system. Finally, silvopasture brings farmer attention to farm woodlots by incorporating portions of these wooded areas into the main financial revenue streams of farms.

CONCLUSIONS

There is a timely need for applied research and education related to silvopasture management in the Northeastern United States. A viable and very common practice around the country and world, silvopasture holds a great deal of potential to benefit Northeastern United States agro-ecosystems and farm profitability. The practice of silvopasture may provide an ecologically sustainable and financially profitable alternative to the longstanding regional practice of pasturing woodlands. There is currently a dearth of information to rely on for informed management of Northeastern silvopastures. A serious effort needs to be made by researchers and extension professionals to develop best management practices for silvopasture if it is going to displace pastured woodlands on regional farms. Like any new technology in a region, adaptive management will be critical to silvopasture adoption in the region.

The use of silvopasture should be seen as an integrated component of farms and not the sole system utilized, as has been studied in other parts of the country (Kallenbach et al., 2009). With all of the recent interest in the Northeast toward silvopasture, now is the time to encourage its adoption. Taking steps to base regional silvopasture, and agroforestry, practices in science will ensure that competitive ecological processes of the system are addressed through management while complementary interactions are maximized.

CHAPTER 1: SILVOPASTURE PRACTICES AND PERSPECTIVES IN THE NORTHEASTERN UNITED STATES

ABSTRACT

The use of silvopasture systems on farms in the Northeastern United States has never been documented. The objective of this study was to gather baseline data to describe silvopasture practices and perspectives in the Northeastern United States. To accomplish this, we investigated the structure, management of, and reasons for use of silvopastures in New York and New England through a series of interviews and inventories on 20 farms purposefully chosen as practicing silvopasture. Thematic content analysis was conducted to summarize interview results and identify trends related to silvopasture practices. Three farmers in this study had been practicing silvopasture on their farms over 30 years; the rest were new to silvopasture in the past ten years. Only three of 20 farmers interviewed in this study had experience practicing silvopasture prior to implementing it on their farms. Forest conversion to silvopasture was the primary starting point for silvopastures observed on regional farms. Orchard, open field edge, outdoor living barn, and plantation silvopastures were also documented on multiple farms. Shade and a desire to maximize use of farm woodlands were primary reasons for silvopasture utilization. This research provides evidence that silvopastures are being used to diversify regional farms. For the practice to be advanced in the region further research is needed on the topic.

INTRODUCTION

The use of silvopasture systems on farms in the Northeastern United States has never been documented. Two syntheses on agroforestry and silvopasture science in North America describe silvopasture systems in all regions of the continental United States except the Northeast (Clason and Sharrow, 2000; Garrett et al., 2004). While it is clear that some regions of the United States, such as the Southeast and Midwest, have a strong history with silvopasture, the occurrence of silvopasture in the Northeast is relatively unknown. Recent publications have called for adoption of silvopasture by farmers in the Northeast and the topic has been highlighted during regional workshops and conferences over the last five years (Carroll, 2011; Chedzoy and Smallidge, 2011a, b).

A stumbling block in the adoption of silvopasture systems in the Northeastern United States may be that there are few publicly known examples of silvopasture in the region. A 2011 publication on silvopasture in the Northeast describes the benefits and general components of silvopasture systems but few specific examples are provided (Chedzoy and Smallidge, 2011b). It is risky for a farmer to adopt a new system without an understanding of its benefits and tradeoffs in the form of established regional examples.

In other areas of the world the adoption of agroforestry practices has been slow due to farmer bias against trees (Neumann et al., 2007) and low landowner knowledge toward agroforestry practices (Barbieri and Valdivia, 2010). Semi-structured interviews with farmers in Colombia indicate that the primary barriers to silvopasture adoption were high establishment costs and lack of knowledge/resources available to farmers about the practice (Calle, 2008). In Argentina, researchers using semi-structured interviews found that 84% of farmers practicing silvopasture would increase the amount of land they have in that form of management if given the opportunity (Frey et al., 2012).

Agroforestry research in the United States provides insight into attitudes toward unconventional farming and forest management practices. In Missouri, it was found that many farm landowners had little knowledge of agroforestry practices yet their interest in some practices, such as silvopasture, was greater than their knowledge (Arbuckle et al., 2009). Another study found that family farmers in Missouri had little understanding of agroforestry practices (Barbieri and Valdivia, 2010). A survey of woodland owners and farmers in Pennsylvania found the barriers to agroforestry adoption to be a lack of ability to experiment, expenses of additional management, and unknown markets for products (Strong and Jacobson, 2005).

The path to ensuring the sustainable management of regional silvopasture systems starts by providing land managers with documented experiences of others to learn from and consider. The objective of this study was to gather baseline data to describe silvopasture practices and perspectives in the Northeastern United States. These data act as a reference point for future scientific inquiry and advancement of silvopasture. To accomplish this, we investigated the structure, management of, and reasons for use of silvopastures in New York and New England through a series of interviews and inventories on farms practicing silvopasture.

METHODS

Interviews

Twenty-two semi-structured interviews were conducted by phone and on-farm with silvopasture practitioners to document the details of, and reasons for, the current use of silvopasture in New York and New England. In addition, we conducted quantitative inventories of silvopasture systems on selected farms. Interviews and inventories occurred in 2014.

A snowball sampling technique was used to identify and purposefully sample farms practicing silvopasture (Patton, 2002). Professionals in the field of silvopasture, cooperative extension agents, and professional farming and forestry organizations were used to locate self-identifying practitioners of silvopasture. Additionally, attendees of the 2011 and 2014 Northeast Silvopasture Conferences who identified as farmers were solicited for interviews. Fifty-two farms were identified through this process as potentially practicing silvopasture. Silvopasture was defined as having intentional and sustainable management of tree crops, livestock, and forage on the same unit of land. Farms for interviews and site visits were selected by the following ranked measures: willingness to offer an interview, number of years practicing silvopasture, multiple types of silvopasture systems integrated in the same farm, and number of acres in silvopasture. Preference for an interview was given to three farms that were practicing silvopasture in states which were under-represented via the above measures, enabling the scope of this research to encompass all states in New England and New York. Of these 52 first identified, 20 practitioners were selected for an interview and 15 of these interviews were conducted on-farm while the remaining five were over the telephone. Three farms were not selected for interviews or site visits due to unwilling participants and the remaining 29 farms not selected for interviews were in their first year or planning stages of silvopasture development. Twenty-three unique silvopastures at various stages of establishment were inventoried on 15 farms. Opportunistically, two foresters with experience managing silvopastures in the region were interviewed in person on farms where they were managing silvopastures.

Interviews lasted between 30 and 120 minutes and interviewees had the opportunity to answer and expand on many questions regarding their perspectives toward silvopasture, farm demographics, and the management of on-farm silvopastures. Interview questions were reviewed by multiple researchers at the University of New Hampshire and Cornell Cooperative Extension for clarity and comprehensiveness. These questions were then pilot-tested for clarity with three silvopasture practitioners prior to implementation. Phone interview questions were consistent with on-farm interviews but included an additional question asking the practitioner to describe the tree and understory species compositions of their silvopastures.

This method of semi-structured interviews is consistent with the methods of a 2010 study in Vermont that addressed the extent and multi-functionality of treed habitats on farms (Lovell et al., 2010), the methods of a New York study which investigated the experiences of farmers selling at markets (Griffin and Frongillo, 2003), and a Northeastern United States study that investigated the opportunities of farm to school programs (Izumi et al., 2010).

To ensure consistency in interview technique, the primary author conducted all interviews. With the permission of the interviewee, interviews were tape-recorded and detailed notes were taken. Upon completion, recorded interviews were transcribed. Interview records were reviewed by multiple researchers (investigator triangulation) to account for interpretation bias (Denzin, 1978; Patton, 2002). Thematic content analysis was conducted to summarize interview results and identify trends related to silvopasture practices (Patton, 2002). Interview results were coded into the following broad categories: demographics, reasons for silvopasture use, silvopasture management (trees, livestock, and forage), and challenges of silvopasture use. Additional coding of results were completed within each main category to quantify similar responses.

Inventories

In addition to interviews, an inventory was conducted in silvopastures on each farm visited to determine overstory conditions and forage species composition. The sampling design was a nested plot design using variable radius sampling for overstory and fixed area plots for understory plants. Sampling intensity varied between (but not within) silvopastures due to time constraints and overstory conditions. Silvopastures with low variability in tree spacing and recently established silvopastures were sampled less intensively than others. Data recorded in the overstory sample included tree species, diameter at 4.5 feet off the ground, and product height. Understory sampling consisted of a percent cover of dominant forage species present, and a tally of non-forage plant species present. Percent of photosynthetically active radiation (compared to full sunlight) reaching the forage level was also collected at plot centers but these data were not collected on farms during days of variable cloud cover due to inconsistent light conditions. Qualitative notes were taken on tree vigor, tree root exposure, and bare soil exposure. Qualitative notes were also taken regarding pasture conditions and management on farms visited. With the permission of each farmer, photos were taken of each silvopasture system.

Inventory data of trees, stand relative density, and forages were summarized and analyzed using Microsoft Excel and NED II, a forest inventory and analysis program available from the US Forest Service (Twery et al., 2005). Inventory data were compiled to include a summary of overstory tree stocking, health, financial value, understory forage species composition, existent non-forage plants, and photosynthetically active radiation. Inventory data and interview transcriptions were used to categorize regional silvopastures into the following groups: uniform spacing with forest origin, patch systems with forest origin, variable tree density systems with forest origin, open field edge silvopastures, plantation silvopastures, orchard silvopastures, outdoor living barns, and a silvopasture maple (*Acer* spp.) sugarbush. Pastured woodlands were found on some farms even though the sampling design purposefully sought out silvopasture practitioners. Systems that farmers perceived as silvopasture but were missing intentional management of tree crops, livestock, and forage were categorized as pastured woodlands. Areas where livestock were kept for multiple months without rotation were also considered pastured woodlands. The exception to this was outdoor living barns which were considered silvopastures but may have been missing the forage component but had direct management of tree health through active livestock rotations.

RESULTS

Farm demographics

Ten of 20 farms had at least one full time farmer with no off-farm employment and the remaining 10 had farmers with off-farm jobs in addition to their farm business. Off-farm jobs were diverse and included professionals in the medical field, lawyers, foresters, and agricultural extension professionals. Farmer experience was also diverse. Farmers had been the principal operator of a farm for an average of 13 years (standard deviation 11 years) with a high of 42 years and low of 2 years. Tenure on their current farm, regardless of being a principal operator, averaged 14 years (standard deviation 13 years) with a high of 44 years and low of 2 years.

Primary farm products were highly diverse between and within farms, although a primary farm product on 16 of 20 farms was some type of livestock for meat. Two farms had primary farm products of dairy cattle and the other two farms' primary products were tree crops, including a tree nursery. Timber sales were cited as additional primary farm product on six of the farms. The size of farms practicing silvopasture varied in both land holdings, 12 to 486 hectares (30 to 1200 acres), percent of land in silvopasture (1% to 32%), and number of livestock.

Four of 20 farmers interviewed were practicing what could be better classified as pastured woodlands. Three farms were pasturing pigs in woodlands and one farm was continuously grazing dairy cattle and horses in wooded areas. Two of the four farms practicing pastured woodlands also had well managed silvopastures being grazed by other species. The differences in pasture management between livestock species will be discussed in more detail later.

Farmer experience with silvopasture

Only three of 20 farmers interviewed in this study had experience practicing silvopasture prior to implementing it on their farms. All of these three farmers' experiences with silvopasture prior to implementing it occurred in other parts of the world; pine (*Pinus* spp.) plantation silvopastures in South America, and orchard silvopastures in Europe or Central America. Four additional farmers claimed to have some knowledge of silvopasture prior to implementing it on their farm. The remaining 14 farmers had no, or extremely limited, prior knowledge and experience with silvopasture before implementing it on their farms. Three farmers in this study had been practicing silvopasture on their farms over 30 years in the region, the rest were new to silvopasture in the past ten years. The longest existing silvopasture documented in this study had been in production for 42 years although the median age of silvopastures in this study was 4 years (this is referring to land managed as silvopasture and not tree age).

Silvopasture was a fairly new concept to most farmers in this study, becoming familiar with the practice over the last decade. However, seven farms had been practicing silvopasture prior to finding out it was an agroforestry practice. For example, one farmer who had been utilizing silvopastures for 30 years had first heard the term when an extension professional in his region suggested he be a part of this study. A misconception that any integration of livestock in a wooded area would be silvopasture was held by four farmers in this study. Additionally, a misconception was found to exist among practitioners in the region that any use of livestock to actively eliminate or manage woody vegetation could be called silvopasture.

Reasons for, timing, and challenges of silvopasture utilization

Farmers were utilizing silvopasture for a variety of reasons (Table 1). Shade was the most commonly stated reason for incorporating silvopastures into farms with 16 of 20 farmers independently citing this as a reason for use. Expanding pasture acreage and diversity was also highly cited by farmers, 14 of 20. Utilizing and incorporating woodlands into primary farming ventures was a reason for silvopasture adoption by 12 of 20 farmers.

Incorporation of silvopasture into farm management systems was also diverse. Farms were primarily utilizing silvopastures during the grazing periods of late-spring, summer, and fall. All farmers in this study used silvopastures during the hot periods of the summer. In one case, silvopasture was the only pasture system used on a farm. All other farms integrated silvopastures with open pastures into their landscape. Some farms reserved silvopastures for certain times of the year, such as hot periods in the summer or inclement winter weather, while others kept them as a patchwork within on-farm livestock rotations. Farmers identified the early spring, “mud season”, as a time when livestock were excluded from silvopastures (although one farm utilized silvopastures year round). Girdling of trees and concerns related to soil degradation were reasons for not utilizing silvopastures in the early spring. During mid-summer and times of droughts farmers were utilizing silvopastures because of a perceived increase in forage availability (Table 1).

TABLE 1: Reasons for, and challenges of, silvopasture utilization by 20 farmers practicing silvopasture in New York and New England. Farmers practicing silvopasture were purposefully identified and interviewed. Farmer may have provided more than one reason for or challenge of silvopasture utilization.

Reasons for silvopasture utilization	*Number of Farmers*
Shade for livestock	16
Expanding pasture acreage and diversity	14
Increased utilization of existing farm woodland	12
Increased forage availability during mid-summer and droughts	12
Diversified livestock diet	8
Overall animal welfare	6
Management of undesired vegetation	5
Winter shelter for livestock	4
Tree health/fertilization	3
Increased farm aesthetics	2
Challenges of silvopasture utilization	---
Fencing establishment and maintenance	9
Lack of knowledge toward silvopasture management	6
Lack of time for silvopasture management	5
Unknown forage quality and management techniques	5
Reduced mobility of machinery	3
Support from agricultural extension organizations	3
Undesirable vegetation	2
Fleece contamination in fiber animals	1
Epicormic branching on trees	1
Monitoring livestock	1

Fencing establishment and maintenance was stated as a challenge by nine of 20 farmers interviewed when asked what their major challenges are when managing silvopastures (Table 1). Lack of knowledge toward silvopasture and lack of time for silvopasture management were cited as challenges by six and five farmers (respectively) of 20 interviewed. Forage management and unknown forage quality was another area farmers expressed as a challenge toward managing silvopastures. One of 20 farmers interviewed was not planning to continue practicing silvopasture into the future. This farmer intended to phase out the practice as his apple trees died out; with goals being to create a better view, increase options for the land, and to make fencing more time efficient. However, the 19 other farmers interviewed were pleased with the practice and 14 of these farmers intended to increase the amount of land on their farm in silvopasture. One farmer planned to establish some type of silvopasture on all of his farm's open pastures. One farmer not planning to increase the amount of land in silvopasture had planned to maintain it in areas with flat ground but discontinue the practice on areas of undulating ground due to challenges related to fencing.

Silvopasture Characteristics

High diversity was found in the type and amount of silvopastures on farms. The amount of silvopastures on farms ranged from <1 hectare (2 acres) to 73 hectares (180 acres), with a median amount of 5 hectares (13 acres) per farm. Sizes of individual silvopastures on farms were typically <1-2 hectares (1-5 acres). Size of silvopastures were highly variable due to the shape of silvopastures and inconsistency between and within farms in how silvopastures were divided during animal rotations.

Forest conversion to silvopasture was the primary starting point for silvopastures observed on regional farms (Table 2). The most common of these was a conversion to uniform tree spacing. In these systems mature hardwood, softwood, and mixedwood forests were heavily thinned from below leaving well-formed co-dominant and dominant stems as residuals. Oak, maple, and eastern white pine were the most common species favored as residuals in silvopasture converted from forests. Farmer goals for these species were primarily timber, but in the case of oak, acorns were also favored by many farmers as a livestock supplement. Relative density of forests converted to uniformly spaced silvopastures were between 25% and 82%, with an average relative density of 49%. Also notable in forest conversions was the persistence of non-forage species, for example patchworks of hay-scented fern (*Dennstaedtia punctilobula*) were found persisting in a silvopasture converted from a forest over 20 years prior.

TABLE 2: Type of silvopasture systems found on 20 farms in New York in New England purposefully identified. In some cases, multiple types of silvopasture existed on the same farm. Silvopasture systems were described through interviews and on-site inventories.

Silvopasture type	*Number of Farms*
Forest conversion to uniform tree spacing	13
Open field edges	7
Orchards	6
Forest conversion to patch tree spacing	5
Outdoor living barns	4
Forest conversion to irregular tree spacing	3
Hardwood plantations	2
Conifer plantations	1
Maple sugarbush	1

A patched grouping of residual trees was utilized in five silvopasture systems converted from forestland. Patch sizes were small, <0.25 ha (<1ac) and highly variable in shape. Multiple patches of trees were interspersed within similarly sized patches of open pasture in these systems. Farmer objectives regarding grouped tree retention in silvopastures included both working with pre-silvopasture quality tree distributions, ease of creation, and ease of management. Tree spacing was so heterogeneous in three hardwood silvopastures that these were classified as irregular tree density due to their difference from both uniformly spaced and patch systems.

Seven farms in this study were incorporating silvopastures into the edges of open pastures and/or hay fields (Table 2). Encroachment of forestland into open fields is a challenge in areas with a patchwork of forests and fields. Fallen limbs and trees from forest edges into open pastures, when not removed, prevent mowing of field edges and enable forest encroachment. To utilize this encroachment, some farmers had converted overgrown field edges into silvopastures. Others had converted portions of forests adjacent to open pastures to silvopastures in an effort to diversify the shade conditions of regularly used open pastures. Grazing partitioning of these edge silvopastures contained both open areas and wooded areas, as opposed to grazing the silvopasture edge separately from the open pasture area. Timber, firewood, and mast were the primary product goals for trees in edge silvopastures. A managed field border was also valued for aesthetic reasons by practitioners.

While some field edge silvopastures had a fairly uniform tree spacing between an open pasture and forest edge, others had a gradual increase in tree density from open pasture to forest edge. Some farmers put high tensile electric fence inside a closed canopy forest edge to avoid grounding problems from herbaceous understory plants (shade from the forest suppressed herbaceous plant growth that would ground out electric fences). To establish forages in these edge silvopastures, farmers primarily relied on volunteer grasses from adjacent pastures.

Three types of plantation silvopastures were observed in this study. One, conifer plantations, were being utilized as outdoor living barns and will be discussed in a following paragraph. The other two types were hardwood plantations. Two farms had established black walnut (*Juglans nigra*) in open pastures and were utilizing the plantations as a silvopasture. These were similar to systems described in the Midwestern United States but had denser tree spacing for timber production (Harper, 2001; Zhai et al., 2006). Black locust was the other hardwood silvopasture plantation documented. Trees were being grown primarily for use as fence posts and harvested through commercial thinnings at years 15, 20, and 25. Regeneration of the system was originally through tree seedlings but the next cohort was being established through a coppice system.

Four farms in this study were utilizing outdoor living barns (Table 2). Outdoor living barns are silvopasture systems in which tree density is maintained at a high level to maximize the amount of shelter that trees provide to livestock. This can lead to an accepted lack of forage in the system. Forages in all of these outdoor living barns documented were very sparse or non-existent. Outdoor living barns maintained areas of dense conifers for the purpose of producing timber or fence posts, in the case of northern white cedar (*Thuja occidentalis*), while also providing shelter for livestock during exceptionally cold periods of the year. Farmers stated that outdoor living barns were not utilized as permanent winter paddocks nor did these areas experience livestock pressure during the spring thaw of frozen ground. One farm maintained an outdoor living barn to provide shelter and biting fly relief for livestock during the summer grazing period.

Six farms in this study incorporated livestock into orchards as a form of silvopasture. Farmers stated the value of these systems were fertilization to trees, grass management, livestock nutrition, and reduction in rodent habitat. Orchards were primarily comprised of apple trees (*Malus* spp.) and, in some cases, with lesser components of other fruit or nut trees. Farmers were using fruit products from orchards for on-farm consumption, direct marketing to consumers, livestock feed, and scion wood. Tree spacing in orchard silvopastures varied but it was typically uniform with space between tree crowns.

Primarily sheep or cattle were incorporated into orchard silvopastures by grazing in the summer months, and in the fall after excess fruit has dropped. Farmers grazing sheep in orchard systems did not express a fear of damage to fruit trees from livestock while farmers utilizing cattle stated the importance of short grazing periods to avoid tree damage in orchards. Tree damage by cattle was through foliage consumption and breaking of branches. Regeneration of new fruit trees was being accomplished through individual tree protection mechanisms. One unexpected system found on farms was the integration of sheep and highbush blueberry (*Vaccinium corymbosum*) production. Two farms had well established areas of commercial highbush blueberry and both were incorporating them with one to two day rotations of sheep followed by monthly periods of rest.

One farm in this study was utilizing a maple sugarbush as a silvopasture for beef cattle. This farmer has been periodically grazing a herd of around 90 beef cattle through a 6ha (15ac) production sugarbush for over 25 years. Cattle were only introduced to the sugarbush during dry periods of the summer, such as late July and early August. The farmer stated that he intentionally installed sap lines as high as possible to avoid livestock damage. He also considered forage availablilty to be low in the sugarbush due to high tree density.

As part of the snowball sampling method used in this study to identify silvopasture systems, the topic of grazing Christmas tree plantations with sheep arose. One forester interviewed recalled a former client who utilized sheep to graze between commercial Christmas trees in plantations. As the forester described it, lambs were brought in early during the spring and then continuously grazed on large sections, >5 ha (>12 acre), of Christmas tree fields. The continued existence of this system seemed worth investigating even though the client the forester was recollecting had not been in the business since the 1970's. Six professional Christmas tree growers associations were asked to identify any farmers currently integrating livestock with Christmas tree production. Responses were received from three of these organizations and none were aware of any growers practicing this integration. Two of the responses suggested that the practice was not common due to the risk of damage to crop trees from livestock.

Livestock management in silvopastures

Livestock type being raised on farms in this study was diverse and ranged from 1 to 6 varieties of livestock being raised on each farm and incorporated into silvopastures. Livestock incorporated into silvopastures included beef cattle (12 farms), dairy cattle (2 farms), sheep for meat and/or fiber (6 farms), meat goats (3 farms), dairy goats (1 farm), chickens for meat or eggs (4 farms), turkeys (2 farms), and horses (2 farms). Pigs were being used in the establishment phase of silvopastures on 4 farms. Four other farms were raising pigs in wooded areas for monthly or longer periods without rest. Fifteen farms were concurrently raising more than one type of livestock, and nine of these farms were raising more than one type of livestock in silvopastures at various times over the course of a year. Number of livestock was highly diverse between farms with independent highs of 130 beef cattle, 8,900 poultry, and 200 dairy goats. The smaller end of the range for livestock on farms included 2 dairy cattle, 30 poultry, and 9 sheep. Within silvopastures, and on different farms, up to 700 turkeys, 2,550 chickens, 130 beef cattle, and 115 sheep were incorporated.

Only one of 20 farmers interviewed stated they did not currently use rotational grazing techniques when managing livestock, although this farm was planning to transition to a rotational grazing system. What farmers considered to be rotational grazing was highly variable. Some farmers considered moving animals once a year as rotational grazing, while others understood rotational grazing to mean moving animals at least every few days.

To better understand what rotation lengths farmers were utilizing, they were asked directly what rotations were for each type of livestock they incorporated into their silvopastures. Little differences were found in rotations of cattle, sheep, goats, and horses integrated into silvopastures. Rotations used for these livestock in silvopastures ranged from less than 1 day to a maximum of 21 days. The average maximum rotation length for this group of livestock was 4 days. Rotation lengths utilized by farms for pigs ranged from 2 days to 365 days, with an average minimum rotation length of 15 days and average maximum rotation length of 94 days. Poultry were integrated into silvopastures on six farms, but four of these farms simply allowed poultry to free-range into silvopastures. The other two farms integrating poultry into silvopastures rotated them on a one to three day rotation.

Livestock pressure, by animals or animal weight, was unknown by most farmers in this study and all stated that this was highly variable based on pasture sizes and conditions. However, farmers were able to provide an estimate of how many rotations they get out of silvopastures over the course of a year. The range for this was that silvopastures experienced livestock inclusion between once and 15 times a year, with a median of 3 periods of livestock inclusion over the course of a year, winter rotations included.

With the exception of pigs, farmers were using forage height and availability as a measure of when to move livestock into and out of areas. All farmers pasturing pigs, either pasturing woodlands or for site preparation in silvopastures, utilized signs of site or tree damage as indicators for when to move livestock. Site damage included muddy ground, visible soil erosion, and visible soil compaction. Challenges of moving pig fencing, housing, and watering systems were referenced by farmers as a primary reason for long (or no) rotations of pigs in wooded areas. Some farmers identified the pigs as causing damage to trees and lamented not moving them more often, often citing time to move them as the problem factor.

The primary reason for pig incorporation into wooded areas was for the welfare of the pig from the shade of trees and as a form of vegetation management. Farmers saw the forest as a foraging area for pigs to consume roots, nuts, and insects. Ironically, on four farms that raised both cattle or sheep and pigs, cattle or sheep were moved every ½ to 3 days while pigs were moved on multiple week, monthly or yearly schedules. Where pigs were utilized in both the first year of silvopasture establishment and in pastured woodland situations, between 32% and 100% of inventoried trees had some form of basal damage or root exposure due to livestock. Three farms had damage on 100% of the trees in pastures where pigs were incorporated. Additionally, bare mineral soil exposure ranged from 20% to 100% within areas actively pastured with pigs. Farmers did express a desire to improve the management of their pig areas but most were unfamiliar with resources and information to do so.

Farmers did not have many concerns regarding animal health unique to silvopastures, with 12 of 20 farms stating they had no concerns at all. When asked about animal health concerns in silvopastures compared to open pastures 9 of 20 farms explicitly stated that they felt animal health was better in silvopastures, primarily because of shelter and a diversified diet. Farmers expressed the following concerns regarding animal health in silvopastures: predators (3 farms), falling tree branches (2 farms), hunters (2 farms), parasites (2 farms), toxic plants (2 farms), physical injuries (1 farm), and limited visibility and access to livestock (1 farm). Only two of these concerns were realized by farmers interviewed, one being hoof injury to pigs and the other farm having two cows' tails being caught and torn-off by woody vegetation.

Fencing

Electric fencing was the dominant choice for containing livestock in silvopasture paddocks across all farms in this study. Portable fencing and posts were used by most farmers to separate paddocks but the number of strands was different between farms and type of livestock being fenced in. High tensile electric perimeter fencing was incorporated into some silvopastures. Many farmers used living trees for fence posts and a rot-resistant batten was commonly placed between the tree stem and insulator to allow trees to grow with the fence. Only two farms had insulators nailed directly to tree stems. While some farmers were utilizing sawtimber trees for fence posts, others specifically stated they sought out non-merchantable trees to use for living fence posts. Additionally, some farmers were incorporating compression springs into their high-tensile fences to increase flexibility from falling tree limb pressures.

Two farmers discontinued the inclusion of goats in silvopastures due to challenges with fencing of goats in silvopastures. Electric netting was utilized by some farms to contain goats, sheep, pigs, or poultry in silvopastures but farmers using this expressed challenges of tangles with sticks and trees when setting up or taking down. Two farmers discontinued the use of electric netting altogether in silvopastures, in favor of woven wire fences with electric top and bottom strands of high tensile wire. Fixed-knot, grade A paige wire was specifically recommended by one farm because of its resilience to falling tree limbs.

Forage management in silvopastures

Orchardgrass, *Agrostis* spp, *Poa* spp, red clover, white clover, timothy, and *Festuca* spp were commonly observed in silvopastures (Table 3). In newly established silvopastures converted from forests *Agrostis* spp and *Danthonia spicata* were common volunteer grasses inventoried. Forage seeding treatments occurred in 13 of 19 silvopastures converted from forests. In five of these cases hay fed to livestock in silvopastures was used as a forage establishment treatment. Species commonly used in these seeding treatments are found in Table 3. Eleven of 20 farms interviewed were actively seeding forages into silvopastures. Broadcast seeding in the spring and fall and out-feeding of hay in silvopastures were being used to establish forages. Three farms were specifically managing woody browse as a component of forage in their silvopastures, but these farms did not provide specifics in terms of preferred woody browse species.

TABLE 3: Forage and non-woody understory plants occurring in more than 5 silvopasture inventories on 20 farms in New York and New England. Understory plants were sampled using percent cover in fixed area plots within silvopastures.

Common forages	*Common non-woody plants*	*Forages actively managed for*
red clover (*Trifolium pratense*)	sedges (*Carex*spp.)	red clover (*Trifolium pratense*)
white clover (*Trifolium repens*)	ferns	white clover (*Trifolium repens*)
orchardgrass (*Dactylis glomerata*)	brambles (*Rhubus* spp.)	timothy (*Phleum pratense*)
bentgrasses (*Agrostis* spp.)	wood-sorrel (*Oxalis acetosella*)	orchardgrass (*Dactylis glomerata)*
bluegrasses (*Poa* spp.)	dandelion (*Taraxacum officinale*)	ryegrasses (*Lolium* spp.)
fescues (*Festuca* spp.)		diversified woody browse
timothy (*Phleum pratense*)		

Twelve of 20 farmers considered woody invasive alien shrubs as undesirable plants in their silvopastures. A forester interviewed also identified invasive alien shrubs as a concern toward forage and tree regeneration in silvopastures. Eight of these 12 farms specifically named multiflora rose (*Rosa multiflora*) as challenging weed in their silvopastures. Other undesirable plants, native and introduced, that were mentioned by more than one farm are listed in Table 4. In most cases farmers were utilizing concentrated livestock grazing as a mechanism to control undesirable plants but perceived success by farmers was highly inconsistent between farms and between plant species within farms.

As a group, silvopasture practitioners did not amend the soils of silvopastures. Even on farms where soil amendments were common to open pastures, silvopastures did not receive treatments. In two cases, practitioners added lime when converting a forest to a silvopasture but this was a one-time treatment during the first year. Immediate removal of stumps was only found on three forest conversion silvopastures, and farmers cited high costs as a deterrent to removing stumps. Vehicle access to the site was the predominant reason for stump removal. In one case stump removal was required due to conditions of a federal cost-sharing program.

TABLE 4: Undesirable plants stated by more than one silvopasture practitioner in New York and New England. Interviews were conducted on with 20 purposefully sampled silvopasture practitioners.

Plant Species	Common Name
Rosa multiflora	multiflora rose
Berberis thunbergii	Japanese barberry
Fallopia japonica	Japanese knotweed
Celastrus orbiculatus	oriental bittersweet
Rhammus spp.	buckthorn
Lonicera spp.	honeysuckle
Ligustrum spp.	privet
Cirsium spp.	thistle
Carex spp.	sedges
Kalmia latifolia	mountain laurel
spp.	ferns

One farmer removed stumps from all seven of his silvopastures that had been converted from forestland. However, this was done seven to nine years after the establishment harvest for each silvopasture. The farmer stated that stumps were easier to pull after they decayed in place for seven or more years. Stumps were then dragged out using a heavy sled of steel beams or pushed out with a small bulldozer. The farmer then let the stumps sit on the surface for a year to dry and be washed of soil; they were then loaded, by hand, onto a wagon and removed from the site or placed in low areas. This was an innovative system and the observed soil and residual tree damage were less than what was witnessed in silvopastures which were stumped during the establishment year with heavy machinery. Exposure of residual tree roots in new silvopastures occurred because stumps removed during the first year had intertwined roots with residual trees. Four farms were utilizing pigs as a site preparation tool prior to forage establishment, but as mentioned earlier 32%-100% of trees in these silvopastures had physical damage from pigs.

Tree Management in Silvopastures

Farmers were primarily managing trees in silvopastures for sawtimber, firewood, and hard mast/fruit (Table 5). Other management goals for trees in silvopastures are listed in Table 5. Sawtimber produced in silvopastures was for both on-farm utilization and commercial sale. Firewood was intended for on-farm use in all but two farms interviewed, which were selling firewood commercially. Hard mast was commonly managed for in oak (*Quercus* spp.), hickory (*Carya* spp.), and black walnuts (*Juglans nigra*) with the intention as forage for livestock. Soft mast was in the form of apples, some of which were in planted orchards, others were volunteer trees that had been favored during silvopasture establishment from a forest. Apples were considered a benefit for both livestock forage, commercial sale, and on-farm consumption. Trees species/groups stated as favorable by multiple silvopasture practitioners included oak, maple, fruit trees, eastern white pine, and others (Table 5).

Ten of 20 farms in this study have received no direct financial benefit from the trees in their pastures. An additional four farms have only received a financial benefit from trees during the establishment thinning of forests converted from silvopastures. Five farms were receiving direct financial income from trees in their silvopastures, these being a commercial tree nursery, farm with black locust thinned for fence posts, fruit from orchards, and maple sap. One farmer stated the importance of having trees in pastures for mental stimulation while tending livestock in the winter: “But at least if while you are sitting there freezing on a tractor you’re going, ok, I can take this tree, leave this one, leave this one.”

TABLE 5: Tree composition and uses of silvopastures on 20 farms in New York and New England. Tree composition was acquired through silvopasture inventories on 15 farms and phone interviews with 5 other farms. Goals for trees in silvopastures were acquired by interviewing silvopasture practitioners at the 20 farms.

Dominant tree species/groups (Common Name)	*Number of Farms*
Quercus spp. (oaks)	11
Acer spp. (maples)	10
Fruit trees, primarily *Malus* spp. (apples)	8
Pinus strobus (eastern white pine)	4
Carya spp. (hickories)	4
Tsuga Canadensis (eastern hemlock)	3
Commercial nut trees, primarily *Juglans* spp. (walnuts)	2
Robinia pseudoacacia (black locust)	2
Goals for trees in silvopastures	---
Sawtimber	12
Firewood	12
Fruit or nuts	11
Maple sugar potential	4
Wildlife habitat	3
Fence posts	2
Scion wood	1

Six farms had considered actively regenerating trees in their silvopastures, the remaining 14 farms stated that they were not actively regenerating trees at this time. Individual tree fencing was being utilized by six farms to regenerate trees in silvopastures, one farm was also using a coppice system for black locust, and another farm was allowing hardwood sprouts to regenerate in the piles of slash left over from the initial silvopasture establishment thinning.

When asked about concerns regarding tree health in silvopastures nine of 20 farmers stated concerns related to invasive alien forest pests, such as emerald ash borer (*Agrilus planipennis*) and hemlock woolly adelgid (*Adelges tsugae*). Four farmers also found the springtime to be a high risk for tree damage from livestock perceived to be caused by sap flow at this time. Stripping of bark and root damage was of concern by farmers with goats and pigs. Pig farmers recognized that their pigs may be doing damage to their trees, but they were uncertain as to how much damage was being done, if any in some cases. For example one farmer stated: ". . .it's helpful for the pigs to be clearing out spaces that we need cleared but we're not sure that they are mutually beneficial to trees."

In some cases livestock damage to trees was perceived to be caused by a response to nutritional deficiency in livestock. One farmer brought this knowledge of mineral deficiencies with them from silvopasture experiences in Central America ". . .we had sheep in a mango orchard and they were just ripping the bark off of every tree and I tried spraying the trunks with all sorts of stuff and they just still ate it and I read somewhere that they eat bark because it's a mineral deficiency. So I got them a mineral block and it stopped overnight." Many farmers practicing silvopasture were highly aware of tree health issues and actively avoided them, as one farmer put it: "If there's a tree in my pasture I want to take care of it." Another cattle, goat, and sheep farmer expressed the importance of management: "We've never really seen any debarking, or girdling by livestock, at least in areas that are being managed."

Twelve of 20 farms had worked directly with a forester when developing silvopastures, and eight of these 12 found the forester to be supportive of silvopasture. The following statement from a farmer utilizing well managed silvopastures on a cattle farm provides insight into possible differences in land management objectives between a farmer and forester:

> "Initially the first [forester], we had spirited discussions. He was a professional forester from [location removed], a great guy, and I had a lot of respect and I have learned a lot from him. But I don't think he appreciated it [silvopasture], his first love was forestry not cattle . . . I mean that's the whole point really of a forest management plan is for you as a land owner to be able to articulate

> what you want and then the forester can help achieve that. I think my first forester kind of thought I didn't know what I was doing, and to some extent I'm sure he was right. So we had more, uh, spirited discussions about things. The guys who do it now have a bit of sense of what I want and they're, I guess, polite enough to go along with it. The kinds of information I get from a forester I guess are cautionary: about wind throw, and disease, stocking rates, regeneration."

One farmer actively avoided working with a forester in silvopastures, stating that foresters do not know much about silvopasture. Three farmers had switched the foresters they were working with and hired new foresters who were more open to the practice of silvopasture. A forester interviewed in this study provided the following advice: "you've got to have the right farmer with the right frame of mind". He was referring to farmers who want to manage their trees and already demonstrate sound livestock management practices.

Some farmers were pleasantly surprised by the support and ability of the foresters they hired to assist with silvopasture establishment. For example, one farmer who worked with a forester in developing a silvopasture stated the forester was "open to it"; another farmer was surprised at how accommodating their foresters were. A separate farmer specifically hired a forester because the forester had the initiative to read about agroforestry practices when the landowner asked if he'd read <u>Tree Crops: A Permanent Agriculture</u> (Smith, 1929): "He bought it, he went online and bought it and read it, and I thought God this is a forester I want, you know, 'cause he was willing to do that."

The two foresters interviewed in this study stated their involvement with silvopasture was due to demand for the practice from clients. Both foresters had managed forests for farmers who pastured woodlands and one clearly articulated his experience that the continuous pasturing of woodlots caused a lot of damage through soil compaction, girdling, and loss of regeneration. Yet the same forester was positive toward silvopasture: "In theory I think it's a great practice for a lot of reasons. Between invasive species and shortage of pasture and utilizing land that wouldn't be utilized, it's just trying to take that theory into [practice]."

Farmer needs for silvopasture optimization

Three farmers expressed lack of support from agricultural extension agencies for silvopasture as a major challenge they faced in adopting the practice (Table 1). Farmers were especially frustrated when extension personnel confused their silvopastures with poorly managed pastured woodlands. However, the converse confusion also occurred by farmers practicing continuous pasturing of woodlands with pigs and calling it silvopasture.

Areas of research desired by farmers toward silvopasture were diverse (Table 6). Eight farmers particularly requested visuals and case studies of regional silvopastures. Scale of these examples was also identified as important; as expressed by one farmer: "There's some kind of permaculture people who talk silvopasture a bit but it's at such a small scale it's not applicable, you know they have five acres".

TABLE 6: Areas of silvopasture research requested by two or more farmers during interviews with 20 farmers practicing silvopasture in New York and New England.

Requested areas of silvopasture research
Forage/browse quality, selection, and management
Tree care, regeneration strategies, and management
Overall silvopasture management
Soil properties and management
Best management practices for pasturing pigs
Vegetation management using livestock
Fencing systems
Quantification of animal health and production
Environmental benefits
Management of orchard silvopastures
Air temperature dynamics
Economics

When asked what resources they would utilize to learn about silvopasture, farmers varied greatly in their responses. The consistency between all farmers was that they wanted resources with visuals of regional silvopastures and that time was a challenge in obtaining educational resources toward silvopasture. Farm tours were cited as important educational opportunities by 12 farmers, but timing of these tours was cited as a challenge. Farmers were split between desiring online resources such as webinars and web pages while others “don’t like reading the damn internet” and want resources “on a paper, printed.” Extension personnel, conferences, and other farmers were cited as educational resources farmers would utilize in obtaining information about silvopastures.

DISCUSSION

Silvopasture systems being used in New York and New England are highly diverse in terms of structure and reasons for use. For example one silvopasture consisted of 100% eastern hemlock for the primary reason that the farmer enjoyed the look of eastern hemlock. Tree density and spacing differ between silvopastures, and in some cases within silvopastures. Coupled with this, farmers goals for the trees in their silvopastures are multiple and on-farm use is often one component. Forages in these systems are also highly variable and seem to be highly dependent on multiple site conditions. However, across the region forage species observed in silvopastures were similar to those commonly found in open pastures on similar quality soils.

Well managed silvopastures in this study were those in which the farmer had a direct value toward the tree crops. For example, orchard silvopastures and high value hardwood plantations were well managed likely due to farmers realizing a direct financial benefit from trees. Additionally, farmers with productive silvopastures were all utilizing short rotations for livestock followed by long periods of rest. This was also the case with outdoor living barns, which farmers were utilizing for livestock shelter for short periods of harsh weather. Areas of future research should compare the shelter benefits and tradeoffs of silvopasture compared to manufactured shelters for different species of livestock. Based on these results it is clear that land managers have many options for integrating silvopastures into farm landscapes.

Many misconceptions regarding silvopasture were discovered as part of this research. Primarily, a confusion exists among farmers as to what silvopasture actually is. Specifically, confusion exists between silvopasture and any incorporation of livestock into areas of trees or woody vegetation, regardless of tree health or livestock management. Of significant concern were farmers calling highly damaging pastured woodland practices silvopasture. This confusion poses a severe risk to the successful adoption of the practice in the region as it furthers the confusion between farmers, extension professionals, and foresters as to what silvopasture really is. Worse yet is the degradation happening to woodlands and going unrealized by farmers who may believe they are doing the “right” thing. A clear and consistent message toward what makes successful silvopastures coupled with best management practices needs to be developed for silvopasture in the Northeastern United States. Low landowner knowledge toward agroforestry practices is not unique to the Northeastern United States (Barbieri and Valdivia, 2010), and farmer education has been shown to lead to successful agroforestry adoption (Frey et al., 2007).

While studies from other parts of North America have documented a farmer bias against trees (Arbuckle et al., 2009; Barbieri and Valdivia, 2010; Neumann et al., 2007; Raedeke et al., 2003), all but one farmer participating in this study strongly desired trees as a component of their pastures. However, farmers in this study also valued trees for multipurpose uses. A study in Missouri found a divide between farmers with a strong “conventional farming identity” and those who were also interested in the recreational and environmental aspects of land ownership, the latter group being more likely to adopt agroforestry practices (Arbuckle et al., 2009). It may be that this divide does not exist in the Northeastern United States or silvopasture practitioners in this study fell in the latter group. Regardless, while farmers interviewed in this study favored trees, many were unaware of how to manage them. A limitation to using purposeful sampling is that it intentionally favors sampling of a single group. This study did not seek out non-adopters of silvopasture who were familiar with the practice. Follow-up studies should consider addressing this group to identify concerns regarding silvopasture that inhibited adoption.

An additional challenge related to silvopasture and pastured woodlands came out in the results of this research. Farmers typically prioritized the care they give to each silvopasture/woodland component based on their primary economic crop. For example, farmers whose primary farm income was cattle-based would respond to questions about silvopasture management in terms related to cattle production and wellbeing and not mention tree crops or health. The reverse was true when speaking to farmers about silvopasture orchards where the primary economic crop was from fruit. In the cases of pastured woodlands this difference could be extreme; for example, one farm practicing pastured woodlands received $20,000 per year net income from pork but only utilized woodland trees for heating a small home with firewood. This farm recognized the damage being done to forest soils by pasturing pigs on long rotations but the short-term (annual) economics did not dictate caring for their trees.

The use of pigs for site preparation in silvopastures and simple pasturing woodlands with pigs testifies to the confusion around silvopasture and lack of landowner knowledge toward trees. In one case this confusion of terms was so extreme that a farm adopted continuous grazing of pigs in the woods, calling it silvopasture, because they no longer wanted the pigs to damage open pastures. The fundamental problem with pasturing of pigs as seen on farms in this research was that the movement of pigs out of a paddock was reactionary and driven by indicators of site damage, such as heavy soil compaction or damage to trees, and/or persistent breakouts by pigs to find new areas. Movement of pigs out of a paddock should be proactive and before damage occurs.

Ironically, on farms which pastured both pigs and other livestock, the other livestock were moved based on signs of reduced forage availability, such as forage height, while pigs were still moved in reaction to site degradation. This was even the case on farms where pigs were the primary source of income; cattle were moved daily yet pigs were moved monthly. This discontinuity may be the result of farmers needing to bring feed to pigs regardless of site conditions, whereas feed is an extra cost to farms when grazing animals are on pastures which have run out of forage. Additionally, farmers pasturing pigs were doing so by trial and error, yet with their grazing animals farmers were aware of recommended management practices. The major problem with using reactionary indicators, such as bare soil and exposed roots, to determine when livestock should be removed from an area is that the damage has already occurred. Movement of livestock in any silvopasture system must be proactive to avoid site degradation as one year of tree damage can end decades of tree growth, and soil structure as well.

Perhaps it is the strong and long-lived stature of trees which gives farmers the perception that they are resilient to root damage; when in reality the opposite is true as trees will live off their stored energy reserves for a few years before showing signs of decline or mortality. It is forages that tend to be resilient to heavy soil disturbance, although the recovery mechanism is through rapid reproduction, not persistence. Research is clearly needed to investigate the effects of pigs in pasture systems and, if appropriate, develop best management practices for pasturing pigs with trees.

In Europe the use of pigs in treed systems has been going on for centuries, but it is often only in the fall to allow pigs to glean fallen hard or soft mast (Rigueiro-Rodriguez et al., 2009). Lessons from Europe would suggest that the incorporation of pigs into forestland needs careful mitigation. According to German law, pigs are banned from forests unless natural regeneration of beech and oak trees is guaranteed (Rigueiro-Rodriguez et al., 2009). Pigs in European systems are primarily consuming mast, whereas what was witnessed in this research were pigs consuming actual components of trees, primarily roots and lower bark. The pasturing of pigs to forage mast is much less destructive to tree health than the pasturing of pigs that are browsing tree roots. If pasturing implies forage availability and management, then the systems documented here would be best termed rooting or neglect.

There is a desire among farmers to be doing the right thing, despite the destructive nature of pasturing pigs documented here. The challenge is these farmers don't have the resources to determine what the right thing is: "Was I really doing silvopasture or was I just running pigs in the woods?" Timing is a major factor in this degradation and a simple recommendation may be for farmers to set up multiple paddocks for pigs prior to their introduction into silvopastures. Development and maintenance of a sod layer in silvopastures may also help to buffer soil degradation and rooting from pigs. Outreach, be it in a silvopasture setting or not, is clearly needed to improve the sustainability and soil integrity of pasturing pigs.

The desire to do the right thing regarding silvopastures was found among all farmers interviewed, although many were unsure of what that was. Farmers were primarily managing silvopastures through trial and error and based on their own institutional knowledge. Areas of research in relation to silvopastures desired by farmers was diverse and challenges of silvopastures were often very practical and geared toward management. In some cases silvopastures were perceived by farmers as lower production areas but even these farmers desired more information on how to make silvopastures more productive and efficient. Resources need to be developed to assist farmers in managing silvopastures. Best management practices regarding livestock, trees, and forages coupled with case studies and silvopasture demonstration areas would go a long way in ensuring that farmers are integrating functional silvopastures into the regional landscape. Additionally, identifying the benefits and tradeoffs of silvopasture to livestock, the environment, and farming economy is an important regional need.

Twenty-nine farms not chosen for interviews, and 14 farms interviewed in this study were in the beginning stages of silvopasture establishment, suggesting that silvopasture is a budding regional practice. Agricultural extension professionals and researchers are in a unique position to influence the development of silvopasture practices at the beginning stages of their adoption in the region. Farmers were well aware of public education extension efforts toward invasive alien forest pests, suggesting that similar efforts toward silvopasture management would reach the right people. One challenge faced by farmers in this study was an inconsistent message being put out by extension professionals within and between states. For example, three farms were actively working with extension professionals in development of silvopastures, while other farms were very frustrated with the lack of support, and in some cases clear mistrust for silvopasture from extension professionals. Additionally, four farms in this study practicing silvopasture were actually owned and operated by agricultural extension professionals in differing states. In a region as small as the Northeastern United States, it is important that messages toward agricultural practices are consistent between states as regional farms commonly cross-pollinate information. What farmers' desire are resources and people that will help them achieve their goal of silvopasture: “Everything changed for me to be more optimistic about it once I started talking to [extension professional, name removed], up until then it was just something I was butting my head against.”

Silvopasture management recommendations are especially needed as farmers are starting silvopasture regardless of support from their agricultural extension or foresters. Telling farmers to keep livestock out of the woods is not an effective means of avoiding poorly pastured woodlands as one in six hectares of pasture in the region continues to be woodland pasture (National Agricultural Statistics Service, 2012). The demand for shade in pasture seems to outweigh any advice to not integrate livestock and trees. Farmers in the region have a strong land ethic and educating them about functional silvopasture management would serve them and their woodlands well. As a starting point, farmers in this study advised that farms considering silvopasture must already be comfortable with rotational grazing, work with a forester, develop a long-range plan, consider the economics, be prepared to utilize adaptive management, take their time and have patience.

CONCLUSIONS

This study was limited by a small sample size, time constraints for silvopasture inventories, and an intentionally biased participant identification. A regional assessment should be conducted to address the extent and full diversity of silvopasture and pastured woodland practices in the Northeastern United States. This study was also limited in being able to fully assess how well silvopastures were being managed as no management recommendations exist for silvopastures in the region. Future work should investigate appropriate ways to measure tree density in silvopastures as both relative density and basal area were highly variable in this study.

Developments of actual tree stocking rates to optimize silvopasture system productivity could build on this work.

As part of this study farmers were asked about the economics of their silvopastures. Most had not considered the economics of their systems and those that did were unsure. Future research and outreach into the economics of silvopasture would benefit those farmers unaware of their system potential. Open-minded foresters may be key players in this out-reach as some farmers in this study had benefited from working with forests in silvopasture establishment.

Examples exist of decades old, well managed silvopastures in New York and New England, although the majority of silvopasture identified in this study were in the first few years of establishment. Farmers practicing silvopasture found it to be a functional and desirable component of their farm landscape. Confusion between silvopasture and pastured woodlands exists in the region and poses a significant threat to the success of this silvopasture. Specifically, the use of pigs in wooded pastures needs to be addressed as farmers in the region are causing severe damage to woodlands through the pasturing of pigs. Ultimately, the systems incorporating pigs were examples of destructively pastured woodlands and not silvopasture, although the farmers did not always make this distinction. Mast-based silvopasture systems, as can be found in Europe, might be the best considerations for initial information on ways to sustainably integrate pigs and trees.

Regardless of livestock species or silvopasture type, this study provides evidence that silvopastures are being used to diversify regional farms. If best management practices regarding silvopasture are developed it is likely that they will reach and be considered by farmers. Currently, farmer knowledge about silvopastures is homegrown or based on systems from other parts of the world. For the practice to be advanced in the region further research is needed on the topic. Farmers in this study have identified numerous areas of applied research which would help them improve their silvopasture management. Little work has been conducted to quantify the benefits of primary reasons farmers identified for using silvopastures. Research into the integration of farm woodland into agricultural ventures, benefits of shade to livestock, potential for increased forage availability during mid-summer and droughts, and diversified livestock diets would serve the region well. Additionally, outreach should occur on fencing strategies, vegetation management, and forage establishment in silvopasture systems.

Lastly is wise advice about silvopasture given by a farmer in this study: “Pay attention . . . observe . . . and . . . consider those three things: is it working for you, is it working for the animals, is it working for the land” and I’ll add, is it working for the trees?

CHAPTER 2: A COMPARISON OF OPEN PASTURE, SILVOPASTURE, AND THINNED FOREST PRODUCTIVITY DURING THE FIRST TWO YEARS POST HARVESTING TREATMENT.

ABSTRACT

The conversion of forestland to silvopasture is relatively understudied (Garrett et al., 2004). This research is the first to compare the productivity of open pastures, silvopastures, and heavily thinned forests originating from a similar starting point. The objective was to investigate forage production differences between open pastures and silvopastures, and to compare of tree vigor between silvopastures and forests without livestock. To accomplish this an early successional northern hardwood forest in Northern New York was converted to open pasture, silvopasture, and thinned forest in 2012. Six forage treatments were established in each open pasture and silvopasture treatments. Dry matter production of total forages (a combination of planted clover, planted grasses, and volunteer grasses) was significantly greater in open pastures than silvopastures in the first year after establishment (2013), but no significant differences in total forage production were found between silvopastures and open pastures in June or August of year 2 (2014). The orchardgrass treatment consistently yielded the greatest amount of dry matter with year 1, June of year 2, and August of year 2 with mean values of 714 kg/ha, 322 kg/ha, and 385 kg/ha, respectively. The control treatment, where no forages were seeded, consistently yielded the lowest total forage production with dry matter means of 23 kg/ha in year 1, 155 kg/ha in June of year 2, and 150 kg/ha in August of year 2. Orchardgrass percent crude protein was significantly lower in open pastures (10.7%) than in silvopastures (12.9%) in June of year 2. No significant differences in epicormic branching or tree growth were found between silvopasture and woodlot treatments over a two year period post-establishment. Orchardgrass made the most

financial sense of all forages tested because it more than paid for its establishment costs in less than two years. As part of a financial analysis, silvopasture outperformed open pasture and thinned forest treatments in terms of both IRR and NPV. Forage production in silvopastures is clearly competitive with that in open pastures on sites with a similar starting condition.

INTRODUCTION

In the Northeastern United States there has been a growing interest in the conversion of forest land to agricultural land, likely due to an increasing demand for local food and limited supply of operating agricultural land (Bowell and Coffin, 2014; Chedzoy and Smallidge, 2011b). Agroforestry, and silvopasture in particular, has received increasing interest in the forest conversion process in an effort to maximize the ecological and multiuse benefits that forests currently provide in the region (Carroll, 2008). Silvopasture in New York has been promoted by the state’s cooperative extension agency for the past five years and a 2011 publication makes a strong case for the conversion of portions of farm woodlots to silvopastures (Chedzoy and Smallidge, 2011a, b). While this publication provides an overview of the management and structure of forest conversions to silvopasture, it specifically calls for formal research into the establishment and productivity of trees and forages in silvopasture systems.

From a broader perspective, the conversion of forestland to silvopasture is relatively understudied (Garrett et al., 2004). Research comparing forest thinnings with conversion to silvopasture in Missouri suggests that the economic viability of either practice is highly dependent on establishment costs (Godsey et al., 2007). A study in West Virginia compared forage production and soil chemistry in a thinned hardwood forest converted to silvopasture with that in a decades old and established pasture in West Virginia (Feldhake et al., 2010). They found that three year forage production was 41% lower in newly created silvopastures than in open pastures, but that silvopastures had higher photosynthetically active radiation use efficiency (Feldhake et al., 2010). No research has investigated the productivity of silvopastures when compared with open pastures and similarly thinned forests under similar management and establishment conditions.

Significant questions also remain regarding the specifics of forage establishment and productivity in silvopastures converted from forests. Agroforestry research conducted in West Virginia and Missouri has found that productivity and nutrient value of some forages is greater under shade when compared to full sunlight (Belesky et al., 2006; Buergler et al., 2005; Buergler et al., 2006; Lin et al., 2001; Neel et al., 2008). However, other studies have found that heavy shade will decrease productivity and nutrient value of some forages (Buergler et al., 2006; Devkota et al., 2001; Feldhake and Belesky, 2009; Lin et al., 2001). Shade and forage species selection are clearly drivers of forage production, but how trees and forage interact in a silvopasture system remains a question to be investigated.

In this study a northern hardwood forest in New York was converted to open pasture, silvopasture, and thinned woodland. Open pastures and silvopastures were treated with similar forages and management techniques. The objective was to investigate forage production differences between open pastures and silvopastures, and to compare of tree vigor between silvopastures and forests without livestock. This research is the first to compare the productivity of open pastures, silvopastures, and heavily thinned forests originating from a similar starting point. This research also documents the establishment phase productivity of six forage treatments established in open pastures and silvopastures, both newly created from forestland. Additionally, a financial analysis of each system was conducted because silvopasture adoption by farmers is financially driven and hindered by system complexities (Sharrow et al., 1999),.

Specific hypotheses tested in this research were:

1. Forage production was expected to differ by species between open pastures and silvopastures because of light and soil moisture competition between forages and trees in silvopastures.
    - Forage quality of orchardgrass (*Dactylis glomerata*), was expected to be better in silvopastures than in open pastures. Past research has found an increase in the quality of orchardgrass when grown under partial shade (Belesky et al., 2006; Burner, 2003; Peri et al., 2007).
2. Tree vigor and stem quality were not expected to differ between sites managed as silvopastures or woodlots because livestock impact in silvopastures was mitigated through rotational grazing. Reduced tree vigor may be indicated by an increase in epicormic branching. Epicormic branches are new branches developing from suppressed buds in the stem of a tree and can occur when trees are stressed due to thinning (Zobel, 1992). They also reduce the economic quality of a tree's stem because they are considered a defect in resulting sawlogs. One study addressing epicormic branching of trees between a mature forest and an emulated silvopasture found that no difference existed in number of epicormic branches between areas (Walter et al., 2007).

METHODS

Site

This research took place on North Branch Farm, located in the town of Saranac, New York, part of the Adirondack Mountain region. The 2.7 ha (6.75 ac) site was a 50 year old mid-successional northern hardwood forest with an average soil pH of 4.68 prior to manipulation. Species composition was dominated by pole size northern hardwoods including red maple (*Acer* *rubrum*), paper birch (*Betula papyrifera*), white ash (*Fraxinus Americana*), black cherry (*Prunus serotina*), aspen (*Populus* spp.), American elm (*Ulmus Americana*), apple (*Malus* spp.), and American basswood (*Tilia Americana*). Overstory basal area averaged 19 m^2/ha (83ft^2/ac) and was comprised of 2434 stems/ha (985 stems/ac) with a quadratic mean diameter of 9.9cm (2.9in) (Table 1).

TABLE 1: Overstory conditions in silvopasture and woodlot treatments pre-treatment in 2012 and in 2014 two years after a low thinning. Silvopasture treatments were seeded with forages and grazed with cattle between 2012 and 2014. Inventories were conducted at the same plot centers using fixed area plots in systematic random design. Means are reported with (standard errors). Relative density was calculated using NED2 (Twery et al., 2005). n = 36.

Measure	*Pretreatment 2012*	*Post Treatment 2012*	*Post Treatment 2014*
Basal Area/Ha (m^2)	19 (1)	6 (1)	7 (1)
Trees/Ha	2434 (124)	531 (94)	558 (100)
Quadratic Mean Diameter (cm)	9.9	12	12.3
Volume (m^3 ha^{-1})	68 (9)	25 (7)	29 (7)
Relative Density	78% (3%)	21% (3%)	23% (3%)
Photosynthetically Active Radiation (% of full sun)	7.8 (1.3)	21% (3%)	53.1 (5.4)

This site was different than some more urban forests in the Northeastern United States because no invasive alien plants were found during pre or post-treatment inventories. The pre-treatment understory plant community was dominated by *Rhubus* spp., *Solidago* spp., and herbaceous plants typical of northern hardwood forests; few grass species were present. The site's history includes charcoal production in the 1800's followed by dairy cattle pasture until the

1960’s when use ceased and the site gradually reverted back to forest. June precipitation in 2013 (32cm) and 2014 (15cm) was higher than a 20 year average for the region (10cm) (NOAA, 2015). In 2013, July (9cm) and August (5cm) precipitation on the site was lower than the 20 year average (11cm) for both months. Precipitation was higher than the 20 year average in in July 2014 (15cm) but lower than the average in August 2014 (10cm) (NOAA, 2015).

Experimental Design

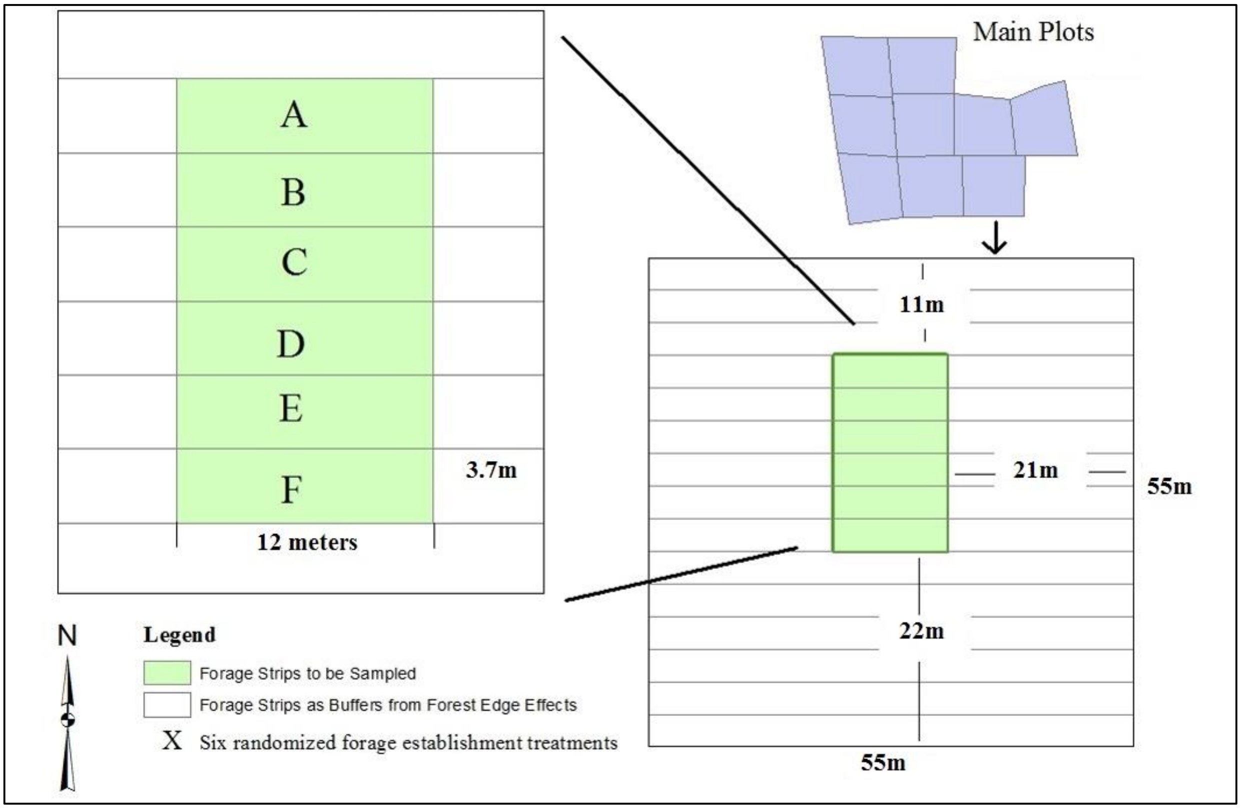

FIGURE 1: Split-plot design of forage establishment treatments in silvopasture and open plots. Sampling of forages occurred in five fixed locations the centers of each strip. No forages were sampled in the buffer zone.

The experimental design was a split-plot randomized complete block (Figure 1). The main plot factor (Table 2) was overstory conditions and there were three treatments: crop tree thinning (woodlot), silvopasture, and open pasture (all trees removed). Each main treatment was replicated three times using 1/3 hectare (3/4 acre) plots. The locations of these plots were randomized within each of the three blocks. The woodlot treatment allowed a comparison of silvopasture to that of a forest without cattle and planted forages. The open treatment allowed a comparison of silvopasture with a newly established open pasture. Response variables measured in main treatments included forage production and orchardgrass quality (woodlot treatments excluded), and tree growth and quality (open treatments excluded). Expenditures related to site establishment to conduct a financial analysis were recorded.

TABLE 2: Main treatment comparisons between woodlots, silvopastures, and open pastures. Initial harvesting and seeding took place in 2012 and grazing occurred in silvopasture and open pasture treatments in 2013 and 2014.

Treatment	*Silvicultural Prescription*	*Harvest Type*	*Forages*	*Cattle*
Woodlot	Heavy Low Thinning	Mechanical, whole tree removal	No Treatment	Excluded
Silvopasture	Heavy Low Thinning	Mechanical, whole tree removal	Seeded	Grazed
Open Pasture	Clearcut	Mechanical, whole tree removal	Seeded	Grazed

Treatments

Main treatments were established in July of 2012. Forest overstory basal area was reduced to 32% of pre-harvest basal area in the woodlot and silvopasture treatments. This was similar to stocking levels on silvopastures from other regions (Devkota et al., 2001; Garrett et al., 2004; Walter et al., 2007). Two of these studies suggest a recommended tree density to maximize forage productivity within a silvopasture of about 30% of full stocking basal area which leads to about 50% canopy closure (Devkota et al., 2001; Garrett et al., 2004). Dominant and well-formed stems were favored in a uniformly spaced low thinning. American elm and white ash retention were not favored due to threats from invasive alien pest species. The majority of stems favored were black cherry and red maple. In open treatments, 100% of trees were removed. Trees were thinned in the woodlot treatment to ensure consistent tree density, and thus similar crown competition, between it and the silvopasture treatment. A no-treatment group was not included because of available land limitations and a desire to maintain similar light dynamics in the overstory and understory between woodlot and silvopasture treatments.

On the first week of July 2012, a logging contractor was hired to harvest the site using whole-tree harvesting techniques. Harvested trees were chipped off-site and sold by the logging contractor for biomass, 64 metric tons/ha of chips (29 tons/ac) were removed and an inventory based estimate of 18 metric tons/ha (8 tons/ac) remained on the site. Cost of harvesting to the landowner was the wood removed, valued at $62/hectare ($25/ac) stumpage, plus $1060 per hectare ($429/ac) paid to the contractor. These costs may have been revenues if a larger area than 2.8 hectares (7 ac) was harvested, but due to economies of scale, harvesting was a cost.

The split-plot factor in this experiment was forage establishment (Figure 1). Forage treatments were established in the silvopasture and open pasture main treatments. Forage establishment treatments included: none (a control treatment), spreading of loose hay, orchardgrass, perennial ryegrass (*Lolium perenne*), Kentucky bluegrass (*Poa pratensis*), and smooth bromegrass (*Bromus inermis*). All four grasses were mixed with white clover (*Trifolium repens*). White clover was broadcast seeded at a rate of 5.6kg pure live seed per hectare (5lbs/ac). Grasses were broadcast seeded at rates of 22.4 kg pure live seed per hectare (20lbs/ac). The loose hay treatment utilized locally-sourced hay bales that were spread thinly over the soil surface to simulate on-pasture feeding of livestock. We selected high quality, first cut, timothy hay with seed heads to ensure a quality and weed free seed source. Forages were broadcast seeded using a hand operated seeder on August 15th and 16th of 2012. The broadcast seeder was calibrated off-site for each species prior to on-site use. Immediately following seeding, cattle, 2,222.6kg (4,900lb) herd weight, were given access to open pasture and silvopasture plots for one day to trample in seed.

In 2013 and 2014 all silvopasture and open treatments were grazed with beef cattle to a forage height of 5cm (2 inches). The duration of grazing was dependent upon the time it took for livestock to graze forage to a height of 5cm (2 inches). The first round of grazing took place in August of 2013 and each 1/3 hectare silvopasture and open plot was grazed by cattle, herd weight of 4,264kg (9,400lbs), for two consecutive days. A June grazing period was not acted upon in 2013 because soils during that time were extremely wet and we did not want to risk damage to young forages or soils. During the first week of June 2014 and the middle of August 2014 a cattle herd weight of 5,443kg (12,000lbs) was grazed on each silvopasture and open plot for two and 1.5 days, respectively.

Data Collection

An inventory of all trees over 1.3cm (0.5in) diameter at breast height (DBH), 1.4m (4.5ft) from the ground, and ground cover flora was conducted in May and July of 2012 to establish pre-treatment conditions. Thirty-six fixed 1/50th hectare (1/20th acre) inventory plots were established for a tree and shrub inventory using a systematic random sample. Tree species and DBH were recorded for each tree. An inventory of residual overstory trees was conducted using the same plot centers in August of 2012 to document post-treatment site conditions. The tree inventory was repeated in May of 2014 to address changes in each treatment. At this time any epicormic branches less than two years old were recorded.

Prior to each grazing period in 2013 and 2014 understory plants and forages were clipped above 5cm (2in) in the center of each forage strip (Figure 1). Forage samples were a systematic aggregate of five $0.093m^2$ subsamples distributed evenly through each forage strip. Individual forages were sorted into the following groups: planted grasses, white clover, volunteer grasses, and other non-woody plants. Samples were then oven dried at 65 degrees C for 24 hours to determine dry matter yield in silvopasture and open treatments. Data on forage production was collected within the center portions of the main and split plots to minimize potential edge effects (Figure 1). The edge buffer was narrower on the north side of main plots due to the southern aspect of the site and forest canopy light dynamics related to the sun's location in the northern hemisphere. Orchardgrass was selected for nutrient analysis in 2014 and composite samples were collected from orchardgrass strips on June 6th and August 11th. These were then sent to the DairyOne Forage Testing Laboratory in Ithaca, NY for crude protein, acid detergent fiber (ADF), and neutral detergent fiber (NDF) analysis.

In August of 2014 percent soil moisture was measured in silvopasture and open pasture treatments at each subsample where individual forage yields were collected. Data were collected after three days of no precipitation. Photosynthetically active radiation (PAR) data were collected using a ceptometer at each forage subsampling site within silvopastures in July 2014. These data were then transformed into a percent of full sunlight based on ceptometer readings in the open the same day.

Data Analysis

All statistical analyses were performed in R (R Core Team, 2014). A split-plot ANOVA model was used to test for significant differences between main treatments and forage treatments (R Core Team, 2014). Prior to analyses, forage data were tested for normality and then $\log_{10}$ transformed. Total forage production was analyzed as a combination of planted grass, planted clover, and volunteer grass dry matter per acre. A least significance difference (LSD) test at alpha 0.05 was used for pairwise comparisons. Orchardgrass crude protein data were normalized using a Log_{10} transformation, but ADF and NDF data were not transformed. A repeated measures ANOVA was used to test for differences in orchardgrass percent crude protein, ADF, and NDF between main treatments and sampling dates. 2014 forage dry matter production data were compared with soil moisture data and PAR data using a Spearman rank correlation.

Overstory tree growth data were analyzed using an ANOVA to test for differences between main treatment and year effects in 2012 and 2014 inventories. Measures of tree growth utilized were basal area per hectare and standing volume per hectare.

Actual financial costs related to all aspects of silvopasture, open pasture, and woodlot treatments were recorded. An initial timber harvesting cost of $1,059 per hectare ($429/ac) was incurred to thin and clear treatments due to a combination of research timing needs, small diameter stems to be harvested, and trucking costs for moving logging equipment to a small harvesting area; 2.8 hectares (7ac) total harvested. These costs were included in one financial model and ignored in another to account for potential variability in initial harvesting costs. Although harvesting was a cost in this study, the possibility for other silvopasture establishments could be to generate revenue, net zero costs/revenue, or a net cost. Initial timber harvesting costs or revenues will vary between sites based on acreage harvested, quality and quantity of timber to be harvested, site operability, and local market conditions.

Livestock production revenues were valued as based on available forage and extrapolated from dry matter forage production per unit area in the different treatments. Financial comparisons were made between main treatments and forage treatments. Costs for forages were calculated based on a grass seeding rate of 22.4kg/ha (20lbs/ac) with an added cost of $17 for 5.6kg/ha (5lbs/ac) of white clover. The cost of hay was assumed to be 30% of its actual because it simulated waste after out-feeding livestock at a rate of 30% waste. Value of forage yield was set to equal the cost of purchasing an equivalent amount of dry hay locally. This was determined to be $0.036 per kg ($0.08/lb) as one 272kg (600lb) round bale of hay at 17% moisture content, thus 226kg (498lbs) of dry matter, costs $40 delivered to the farm.

Financial analysis of main treatments were compared assuming that revenue from pastures would be valued as livestock feed, therefore labor for, and revenue from livestock management was not included. These costs and revenues from livestock would be occurring on the farm regardless of where the animals are pastured. Fencing and watering costs were established based on what was actually incorporated on the site; in this case a poly tank for water and portable polywire fence on permanent cedar posts. Property taxes were based on actual costs incurred in 2014, these remained consistent between main treatments because of complexities regarding how silvopasture fits into current use tax programs when compared to open pasture and farm woodlot. These costs will likely be unique to each farm and situation. Forage establishment values in main treatments were based on the cost and year 2 production of orchardgrass, as this was the most successful of all forage treatments in both silvopastures and open pastures. These values remained consistent between silvopastures and open pastures in the financial analysis because total forage dry matter production was not significantly different between silvopastures and open pastures in 2014.

It was determined that a fourth treatment was needed for the purpose of financial analysis when comparing the three main treatments in this study (open pasture, silvopasture, and woodlot). This fourth was a no-management treatment where timber revenues were projected from the pre-harvest inventory of the site in 2012 to the end of a 30 year rotation using NED-2, an Ecosystem Management Support Program available from the US Forest Service (Twery et al., 2005). For all treed treatments, the FVS northeast variant growth model was utilized to project standing timber volumes in 2042, and the 2014 inventory was used to project silvopasture and woodlot treatments (Twery et al., 2005). Projected volumes were given stumpage values based on 2014 timber prices by species and product. Value of standing timber was extrapolated based on regional stumpage prices published by the New York Department of Environmental Conservation (NY DEC, 2014). Tree regeneration costs were not included in this analysis but it is important to note that they would exist and be variable depending on management goals for the next 30 years.

RESULTS

Forage Production

Dry matter production of total forages (being a combination of planted clover, planted grasses, and volunteer grasses) was significantly greater in open pastures than silvopastures in August of year 1 (2013). No significant difference of total forage production was found between silvopastures and open pastures in June or August of year 2, 2014 (Table 3). In August of year 1 silvopasture total forage dry matter production averaged 255 kg/ha (228 lbs/ac) while open pastures averaged 409 kg/ha (364 lbs/ac) (F=7.983, P=0.0476). Total forage yield for silvopastures and open pastures in June of year 2 were, 187 kg/ha (167 lbs/ac) and 314 kg/ha (280 lbs/ac), respectively (F=2.876, P=0.165). Total forage yields in August of year 2 were 228 kg/ha (203 lbs/ac) in silvopastures and 266 kg/ha (237 lbs/ac) in open pastures (F=0.411, P=0.556).

Planted grass biomasses were not found to be significantly different between silvopastures and open pasture treatments in year 1 (F=0.000, P=0.998), June of year 2 (F=1.804, P=0.250), or August of year 2 (F=0.093, P=0.775). Planted clover also showed no significant differences in treatment effects between silvopastures and open pastures in year 1 (F=0.459, P=0.535) or June 2014 (F=2.674, P=0.177). In August of year 2 planted clover production was significantly greater, at an alpha of 0.1, in open pastures 36 kg/ha (32 lbs/ac) than in silvopastures 9 kg/ha (8 lbs/ac) (F=6.590, P=0.0622).

Table 3: Forage dry matter yields and composition in silvopasture and open pasture treatments in years 1 and 2 of the field experiment. Data are means. Within a row, means sharing the same letter are not different at the $P < 0.1$ level (LSD means test).

	Whole-plot Factor*		Sub-plot Factor						ANOVA		
Year/Forage type	OP	SP	BG	BR	Hay	OG	RG	None	Silvo (S)	Forage (F)	S X F
	kg ha^{-1}				kg ha^{-1}					*P > F*	
Year 1 (Aug. 2013)											
Planted Grass	247.9	209.2	172.5b	193.1ab	0.0c	648.6a	356.9a	0.0c	NS	<0.001	NS
Planted Clover	47.6	31.9	51.2b	121.1a	0.0c	30.9b	35.4b	0.0c	NS	<0.001	NS
Volunteer Grass	113.8	14.3	32.4b	53.5b	241.4a	34.6b	0.0b	22.5b	NS	<0.001	NS
Total Forage	409.3a	255.4b	256.1b	367.7ab	241.4b	714.1a	392.3ab	22.5c	0.048	<0.001	NS
Other Non-woody	636.8	553.3	602.4	559.5	646.2	562.7	386.5	813.0	NS	NS	NS
Year 2 (June 2014)											
Planted Grass	117.8	113.0	121.5ab	129.0ab	50.0b	238.0a	153.8a	0.0c	NS	<0.001	NS
Planted Clover	35.8	12.6	23.3abc	47.6a	34.2ab	9.0bc	29.9ab	1.1c	NS	0.023	NS
Volunteer Grass	160.7	60.9	58.8	130.5	208.9	75.3	37.8	153.8	0.039	0.002	0.001
Total Forage	314.2	186.5	203.1ab	307.2a	293.1a	322.4a	221.5ab	154.9b	NS	0.026	ns
Other Non-woody	408.7	245.6	251.0ab	416.8a	339.4ab	311.0b	197.0b	447.5a	NS	0.077	NS
Year 2 (Aug. 2014)											
Planted Grass	96.2	104.5	128.1ab	54.1bc	34.2cd	326.0a	167.0ab	0.6d	NS	<0.001	NS
Planted Clover	36.1a	8.6b	14.5ab	46.6a	23.8ab	6.9b	35.6ab	6.6b	0.062	0.04	NS
Volunteer Grass	134.1a	78.4b	84.5bcd	125.0ab	214.1a	52.5d	19.1cd	142.4abc	NS	0.014	0.061
Total Forage	266.3	227.5	227.1abc	225.7abc	272.1ab	385.4a	221.8bc	149.6c	NS	0.038	NS
Other Non-woody	751.3	459.6	702.5	653.2	595.1	503.6	462.9	715.6	NS	NS	NS

*Abbreviations are OP, open pasture; SP, silvopasture; BG, bluegrass; BR, brome; OG, orchardgrass; RG, ryegrass.

Volunteer grass dry matter yield was not significantly different between main treatments during year 1 (F=1.648, P=0.269). In June and August of year 2, a significant interaction was found between main treatment effects and forage treatment effects for volunteer grasses. This will be discussed in more detail later. No significant differences in dry matter production of other non-woody plants were found between silvopastures and open pastures during year 1 and both year 2 collections (Table 3).

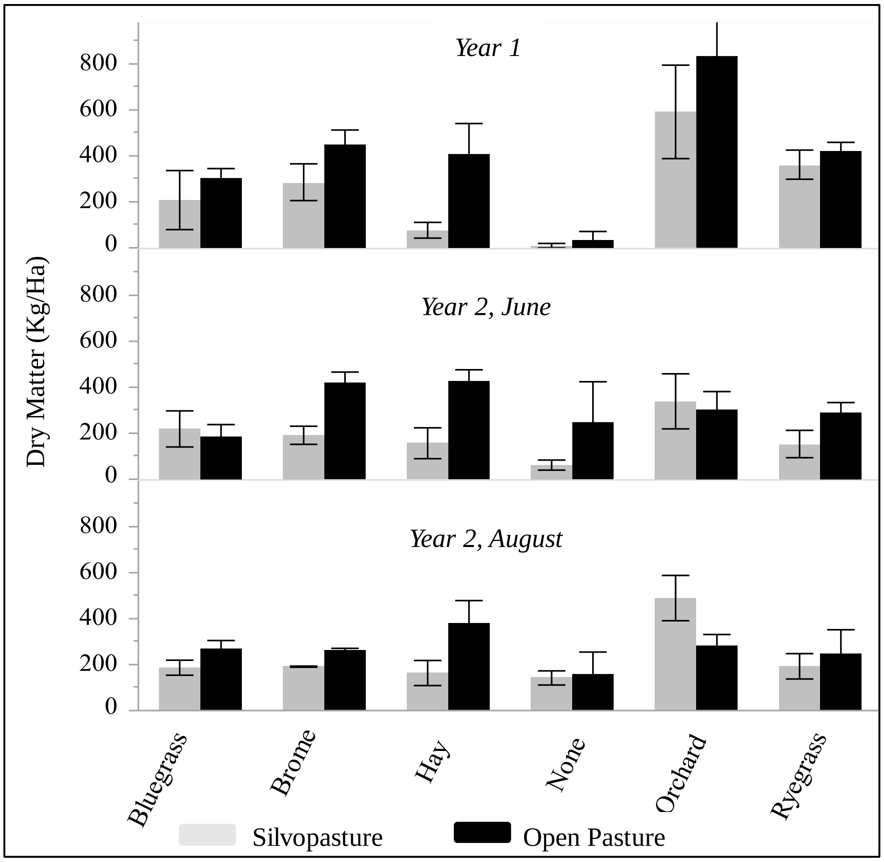

FIGURE 2: Total forage production for six forage treatments (bluegrass/white clover, smooth bromegrass/white clover, loose hay depositing, no forages planted, orchardgrass/white clover, and perennial ryegrass/white clover) in open pastures and silvopastures converted from forests. Total forage production is a sum of planted grass, planted clover, and volunteer grass dry matter yield. Forages were sampled one year post treatment (August 2013), and in June and August two years post treatment (2014). n=3.

Total forage production was significantly different by forage treatments in year 1 (F=10.941, P=<0.001), June of year 2 (F=3.263, P=0.026), and August of year 2 (F=2.958, P=0.038). Table 3 provides pairwise comparisons of yields in each treatments during these periods and Figure 2 displays these graphically. The orchardgrass treatment consistently yielded the greatest amount of dry matter with year 1, June of year 2, and August of year 2 mean values of 714 kg/ha (637 lbs/ac), 322 kg/ha (287 lbs/ac), and 385 kg/ha (343 lbs/ac), respectively. The control treatment, where no forages were seeded, consistently yielded the lowest total forage production with dry matter means of 23 kg/ha (21 lbs/ac) in year 1, 155 kg/ha (138 lbs/ac) in June of year 2, and 150 kg/ha (134 lbs/ac) in August of year 2 (Figure 2).

Significant differences for dry matter production of planted grasses between forage treatments during year 1 (F=111.270, P=<0.001), June of year 2 (F=18.190, P=<0.001) and August of year 2 (F=10.717, P=<0.001). No planted grasses were found in the control forage treatment strips during the year 1 and June of year 2 samples. Less than 1 kg/ha (0.9 lbs/ac) of planted forages were found during the August of year 2 sample. Orchardgrass strips outperformed all other planted forage strips with mean dry matter yields of 649 kg/ha (579 lbs/ac) in year 1, 238 kg/ha (212 lbs/ac) in June of year 2, and 326 kg/ha (291 lbs/ac) in August of year 2. Figure 3 displays performance of each forage treatment relative to others for each sampling period.

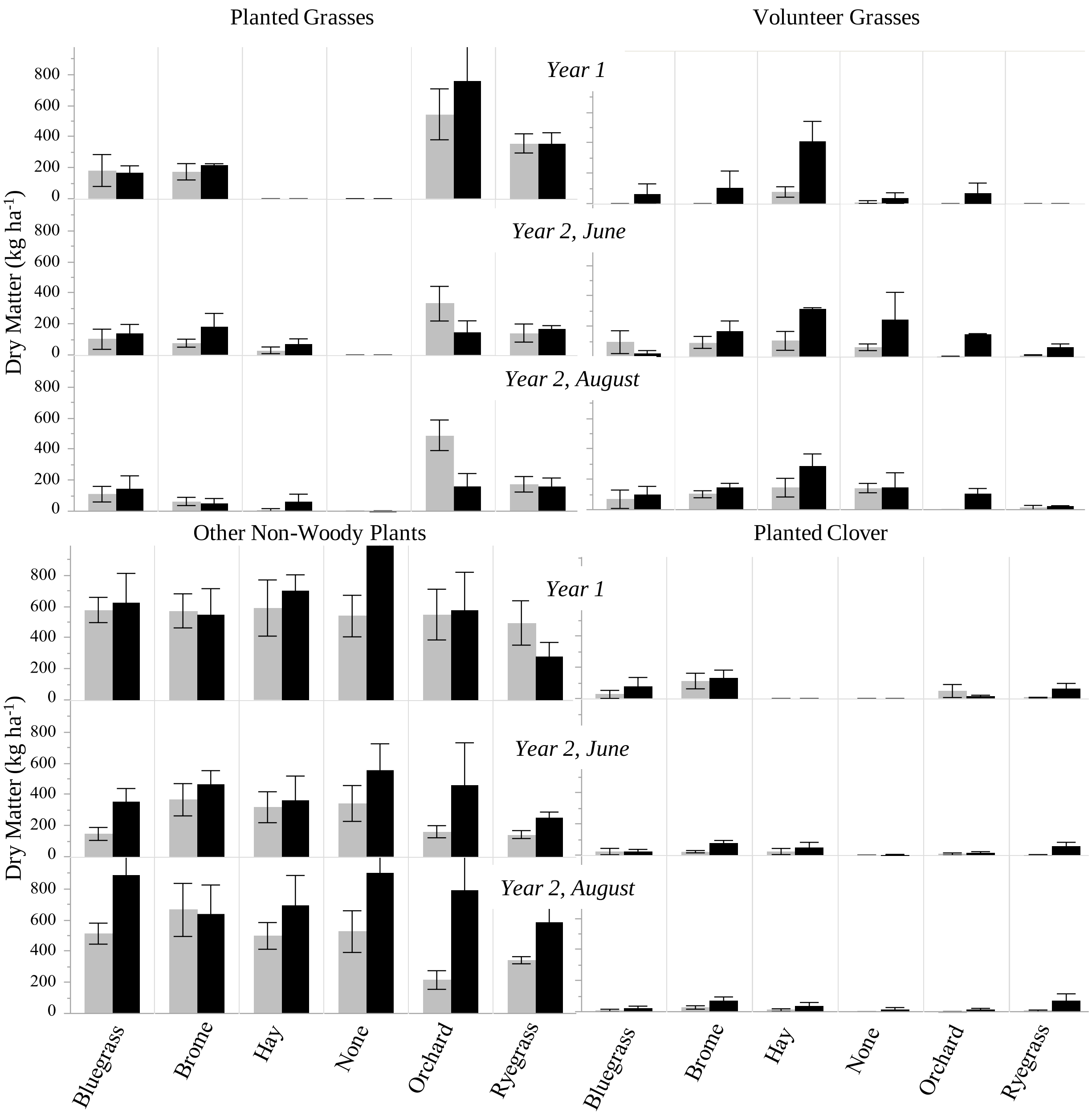

FIGURE 3: Mean dry matter production (kg/ha) of planted grasses, volunteer grasses, planted clover, and other non-woody plants. Data were collected in silvopastures and open pastures after conversion from a forest at three sampling dates, one year post treatment (August 2013), and in June and August two years post treatment (2014). Plants were systematically sampled at the same location in each of six forage treatments: bluegrass/white clover, smooth bromegrass/white clover, loose hay depositing, no forages planted, orchardgrass/white clover, and perennial ryegrass/white clover. Note the relative success of planted orchardgrass in silvopastures compared to other forage treatments. Also not the low production of clover on the site and of volunteer grasses in silvopastures. n=3. Gray bars are silvopasture data, black bars are open pasture data.

Planted white clover was also found to have significantly different yields by forage treatment in year 1 (F=14.492, P=<0.001) and both year 2 samples (June F=3.369, P=0.023; August F=2.898, P=0.040). In year 1 both the hay and control strips had a mean production of 0 kg/ha for clover. Clover production was highest in the brome treatment, 121 kg/ha (108 lbs/ac), during year 1. In June and August of year 2 clover production was again highest in the brome treatment with yields of 48 kg/ha (43 lbs/ac) and 47 kg/ha (42 lbs/ac), respectively (Table 3).

In year 1 volunteer grasses were found to be significantly affected by forage treatment (F=9.041, P=<0.001). Pairwise comparisons for this sampling date indicate that significantly more volunteer grasses were found in the hay treatment than any of the others, (Table 3). Significant interactions were found between main treatments and forage strips in year 2 (June F=6.303, P=0.001; August F=2.550, P=0.061). Figure 3 shows the dry matter yield of volunteer grasses between main treatments and forage treatments for each sampling date in year 2. Orchardgrass strips in the silvopastures produced significantly less volunteer grass dry matter than that of orchardgrass strips in open pastures. Open treatments and control and hay strips in silvopastures yielded the higher end of volunteer grass dry matter in year 2 (Figure 3).

No significant differences were found between forage strips for other non-woody plants in year 1 (F=0.699, P=0.630), June of year 2 (F=2.365, P=0.077) and August of year 2 (F=1.490, P=0.237). The 0.1 level significance in June of year 2 was due to significantly more dry matter production of non-woody plants in the control, 448 kg/ha (400lbs/ac), and brome strips, 417 kg/ha (372lbs/ac), than in orchardgrass, 311 kg/ha (277lbs/ac), and ryegrass, 197 kg/ha (176lbs/ac) strips.

Forage Relationships with Light and Soil Moisture

TABLE 4: Spearman rank correlations for dry matter yield of forages in silvopasture treatments with % of full sunlight and relative % soil moisture in the second year after establishment. Planted clover, planted grasses, volunteer grasses, and other non-woody plants were clipped in June and August and weighed after being oven dried. Total forage is the sum of planted clover, planted grasses, and volunteer grasses. Mean percent full sunlight and % soil moisture were sampled at each forage sampling location. *Indicates significance at p=0.05 or better

Sample Group	**Mean Dry Matter Yield (kg ha^{-1})**	**Percent Sunlight** Spearman ρ	Prob>|ρ|	**Soil Moisture** Spearman ρ	Prob>|ρ|
June of Year 2 (2014)					
Planted Clover	12.6	-0.166	0.118	0.350	<0.001*
Planted Grasses	113.0	0.086	0.418	-0.041	0.700
Volunteer Grasses	60.9	-0.033	0.760	0.204	0.054
Total Forage	186.5	0.006	0.957	0.190	0.073
Other non-woody	245.6	-0.003	0.975	0.227	0.031*
August of year 2 (2014)					
Planted Clover	8.6	-0.085	0.429	0.434	<.001*
Planted Grasses	140.5	0.057	0.593	-0.075	0.481
Volunteer Grasses	78.4	0.013	0.905	0.029	0.788
Total Forage	227.5	0.069	0.520	-0.019	0.860
Other non-woody	459.6	0.003	0.978	0.319	0.002*

No significant correlations were found between percent available sunlight and dry matter production of forages or other non-woody plants within silvopastures (Table 4). In both silvopastures and open pastures during June of year 2 soil moisture was positively correlated with dry matter production of planted clover (Spearman p = 0.350, P=<0.001) and other non-woody plants (Spearman p = 0.227, P=0.031). A similar positive correlation with soil moisture was found for these two yields in August of year 2; planted clover (Spearman p = 0.434, P=<0.001) and other non-woody plants (Spearman p = 0.319, P=0.002). No correlations were found between planted grasses and soil moisture in June or August of year 2 (Table 4). Volunteer grasses were significantly and positively correlated with soil moisture at the 0.1

significance level (Spearman p = 0.204, P=0.054) in June of year 2, but no correlation was found in August of year 2 (Table 4).

Forage Nutrition

Nutritional value of orchardgrass was compared between main treatments in June and August of year 2. Main treatment effects were not significant for percent ADF (F=0.119, P=0.747) or percent NDF (F=1.95, P=0.235). Sampling date was significant for percent ADF of orchardgrass (F=13.676, P=0.021), but not for percent NDF (F=0.551, P=0.499). Mean digestibility values of ADF were lower in June (35.7%) than in August (39.3%). NDF values were 62.1% in June and 61.2% in August.

An interaction, at the 0.1 significance level, was found for percent crude protein of orchardgrass between main treatment and sample date (F=6.155, P=0.068). Orchardgrass percent crude protein was significantly lower in open pastures (10.7%) than in silvopastures (12.9%) during June. June silvopasture means were statistically similar to open pasture (12.6%) and silvopasture (13.6%) percent crude protein means in August.

Tree Growth and Stem Quality

No overstory tree mortality or new epicormic branching were found in the 2014 inventory. Therefore comparisons between main treatments were not conducted. Stem mortality did occur in both silvopasture and woodlot treatments but due to a small frequency of occurrence those trees did not fall within inventory plots. No significant differences were found between silvopasture and woodlot treatments for basal area per hectare (F=0.973, P=0.380) and standing volume per hectare (F=0.647, P=0.466) over the two year period. Basal area per hectare of treatments was less in 2012, 6 m^2 ($26ft^2$/ac), than in 2014, 7 m^2/ha ($30ft^2$/ha) (F=124.640, P=<0.001). Merchantable volume increased from 25 m^3/ha (357ft^3/ac) in 2012 to 29 m^3/ha (414ft^3/ac) in 2014 (F=35.302, P=0.004).

Financial Analysis

Net present value per hectare, in 2012 dollars, was analyzed for each forage establishment treatment in order to determine which was most financially applicable for inclusion in main treatment analysis. Table 5 shows the net present value of forage production and costs on the site between 2012 and 2014. The orchardgrass, hay, and control treatments had positive net present values for the three year timeframe of this study; respective values being $72.90, $36.46, and $54.49 per hectare ($29.51, $14.75, and $22.05 per acre).

TABLE 5: Forage cost/revenues per hectare in 2012 NPV, assuming a discount rate of 3% for six forage treatments in open pastures and silvopastures converted from forests in 2012.

Forage Treatment	*Seed cost 2012*	*Seeding labor 2012*	*Total forage production 2013*	*Total forage production 2014*	*Total NPV*
Bluegrass/Clover	$165.56	$12.36	$43.85	$71.51	($62.56)
Brome/Clover	$205.10	$12.36	$62.97	$88.60	($65.89)
Hay	$98.84	$0.00	$41.34	$93.96	$36.46
None	$0.00	$0.00	$3.86	$50.63	$54.49
Orchardgrass/Clover	$154.69	$12.36	$122.28	$117.66	$72.90
Ryegrass/Clover	$133.93	$12.36	$67.17	$73.69	($5.42)

( ) indicate negative values

TABLE 6: Per hectare cost/revenue structure for a 30 year projection of four forest treatments: O= Open pasture, S= Silvopasture, W= Woodlot, N= no-management. All 2012 values are those actually realized on the site. Forage revenue is based on mean orchard grass production in 2013 and 2014.

Action	*Actual $*	*Years*	*Treatments*
Establishment Harvest	(428.57)	2012	O, S, W
Property Taxes	(20.00)	Annually	O, S, W, N
Orchardgrass seeding	(67.60)	2012	O, S
Fence and water infrastructure	(75.00)	2012, 2027	O, S
Forage Revenue	50.97	Annually (after 2012)	O, S
Timber Revenue	2,015.10	2042	N
Timber Revenue	1,370.83	2042	S, W

( ) indicate negative values

Table 6 describes the cost and revenue structure used in financial analysis of main treatments. Orchardgrass was chosen for inclusion into main treatment financial analyses. Silvopasture yielded the highest NPV values and the second highest IRR at 6.4% (Table 7). The no management scenario, which projected timber volumes in 30 years assuming no initial harvest in 2012, yielded the highest IRR at 6.9% and second highest NPV values (Table 7). Open pasture had an IRR of 2.6% and negative NPV values (Table 7). The woodlot treatment yielded the lowest IRR (1.2%) and NPV values (Table 7).

TABLE 7: Internal rate of return (IRR) and net present value (NPV) per hectare at multiple discount rates, with and without initial timber harvesting costs, for four land management options. Silvopasture consistently yielded the highest NPV of all options due to annual and long-term sources of revenue. No management was financially competitive with silvopasture when initial timber harvesting costs were incurred.

Including establishment harvest cost				
		NPV/hectare		
Treatment	**IRR**	3%	4%	5%
Open Pasture	2.6%	($77)	($231)	($356)
Silvopasture	6.4%	$1,277	$773	$391
Woodlot	1.2%	($662)	($883)	($1,033)
No Management	6.9%	$1,003	$607	$327
Not including establishment harvest cost				
		NPV/hectare		
Treatment	**IRR**	3%	4%	5%
Open Pasture	18.2%	$951	$787	$653
Silvopasture	19.2%	$2,306	$1,987	$1,552
Woodlot	4.8%	$366	$135	($24)
No Management	6.9%	$1,003	$607	$327

( ) indicate negative values

Due to the high variability in possible initial timber harvesting costs for pasture establishment this same model was run for open pasture, silvopasture, and woodlot treatments assuming no initial timber harvesting costs, such as may be realized in a commercial thinning. With these adjustments, silvopasture yielded the highest returns with an IRR of 19.2% and maintained the highest NPV values (Table 7). Open pasture followed with an IRR of 18.2% and the second highest NPV values (Table 7).

DISCUSSION

Forage

It is evident that the dry matter production of forages and other non-woody plants are affected differently in silvopastures and open pastures. The two exceptions were total forage production in year 1 and volunteer grass yield in June of year 2. While it has been found that too much shade has an effect on forage productivity (Buergler et al., 2006; Devkota et al., 2001; Feldhake and Belesky, 2009; Lin et al., 2001; Lin et al., 1999), Spearman rank correlations in this study found no relationship between shade and forage production. It is likely that the tree density of the silvopastures in this study was low enough not to inhibit forage production through shading. The silvopastures received, on average, 60% of available PAR, meaning 40% shade was realized by forages. In a study of forages and shade, Lin et al (1999) found that cool season grasses were inhibited under 80% shade but not when grown under 50% shade. This is similar to the findings in another study where forage yield was reduced under 70% shade but not under hardwood trees (DeBruyne et al., 2011). The results presented here suggest that with equal starting conditions, total forage production under low tree density silvopastures will be similar to that under open pastures during the first two years post establishment (Figure 2). More research is needed into the effect of trees on forages in silvopasture systems. Additionally, the long-term dynamics of forage production in silvopastures when compared to open pastures need to be investigated.

Total forage production of silvopastures in year 1 was an exception to similarities in forage production between silvopastures and open pastures. During this time open pastures produced significantly more forage than silvopastures. It is likely that total forage production was less in silvopastures due to a slower colonization rate of silvopastures by volunteer grasses during the first year after timber harvesting. As can be seen in the means, and even though not statistically different, volunteer grasses produced 114 kg/ha (102lbs/ac) of dry matter in open pastures and only 14 kg/ha (13lbs/ac) of dry matter in silvopastures in year 1 (Table 3). The additive effect of volunteer grass production, with much smaller differences in planted grass and clover production between treatments, may explain the difference in total forage production in year 1.

In year 2 volunteer grasses had become more abundant in silvopastures, evening out the disparity between the main treatments (Table 3). It is possible that volunteer grasses took more time to colonize the site due to a lesser ability to compete with trees for moisture during the early part of year 1. Spearman rank correlations (Table 4) suggest a correlation between volunteer grass production and soil moisture in June of year 2. There may also have been less available microsites in silvopastures for volunteer grasses to germinate on. Soil disturbance was less in silvopastures around areas of residual trees. The most abundant volunteer grasses on the site were *Agrostis perennans*, *Agrostis scabra*, *Agrostis gigantea* and *Danthonia spicata*, all native colonizers of disturbed soils. Figure 3 shows the relatively greater production of volunteer grasses in hay and control forage treatment strips in silvopastures for the June of year 2 sample. These were statistically greater than volunteer grass yields in the orchardgrass strips in silvopastures; orchardgrass being the highest yielding (and thus most competitive) of planted forages in silvopastures.

Planted forage production was clearly competitive in both silvopastures and open pastures, supporting the findings of other studies which suggest cool season grass production under silvopastures is similar to that under open pastures. Specifically, orchardgrass stood out as the highest producer in both silvopastures and open pastures. In many cases it produced more than twice what other forages did. One reason orchardgrass is well suited to a forest conversion site is because it is relatively easy to establish (Balasko and Nelson, 2003). In year 2 orchardgrass also showed its ability to respond to grazing by producing more in the August sample than in the June sample. This is especially valuable if silvopastures are to be used for heat-stress reduction during mid-season grazing.

However, yields of orchardgrass were much lower than that of orchardgrass in other studies. For example, orchardgrass planted on fine loamy agricultural soils in Iowa annually yielded 2252 kg/ha (2009lbs/ac) and 3639 kg/ha (3247lbs/ac) of dry matter in a two year study, although these plots were fertilized after the establishment year and four samples were collected over a longer growing season (Sleugh et al., 2000). An alley cropping study with orchardgrass in Arkansas also found higher yields than documented here, with dry matter production values near 1200 kg/ha (1071lbs/ac) for multiple treatments (Burner, 2003). Again, the site was fertilized during the experiment and yields occurred over a longer growing season. The soil pH of this site was also higher, ranging from 5.3 to 5.7 and indicating that nutrients were more available.

Yields of other forages on the site were also low, yielding less than 200 kg/ha (178lbs/ac) per sampling date. While bluegrass, smooth brome, and ryegrass may be desirable for reasons other than productivity, the results of this study suggest that they’re not the best choice for forage establishment. One exception is perennial ryegrass in the open treatment group, which was competitive with orchardgrass production in open pastures. Regardless, yields of forages in this study were lower than that of studies in other regions. These low yields are likely a factor of poor nutrient availability and low pH, as this site had not been fertilized or in agricultural production for at least 50 years. Additionally, the soils of the Adirondack region of Northern New York are sandy and low in nutrient-holding capacity, decreasing the inherent maximum potential production, even on the best sites. However, even with low productivity orchardgrass made the most sense from a financial perspective; paying for its establishment costs in less than two years (Table 5).

One thing to note is the low productivity of white clover across the site. There was a gradual decline in clover production in silvopastures between year 1 and both year 2 samples. Clover yield and persistence may have been low due to the low pH, 4.6, of these sites. Most clovers have a preferred pH of greater than 6.0 (Sheaffer and Evers, 2007). Soil amendments, not used in this study, may be able to enhance the production of white clover in newly established pastures.

The control forage establishment strips, where no forages were planted or hay was put down, consistently yielded the least amount of total forage in both silvopastures and open pastures. This is an important finding as cattle were used for production on the site and woody plant vegetation management. With the lack of grasses in the control strips there was much less for cattle to eat. From a systems perspective, it may be highly undesirable to subject livestock to newly created pastures if no forages are planted, as there will be very little for them to eat, and what they have to eat will be primarily volunteer grasses (Figure 3).

Other non-woody plant dry matter yield seemed to be little affected by main or forage treatments in this study, and although the mean yield of these plants was consistently lower in silvopastures than open pastures, this difference was not significant. The non-woody plants sampled were not desirable cattle forage; they were primarily *Rhubus*, *Solidago,* and *Carex* species. Depending on the type and needs of livestock in the system, the production of these non-woody plants may be of importance for grazing. More time will be needed to determine if the main treatment has an effect on production of this group. It is expected that with intensive grazing these plants will decline over time.

Forage Quality

The results presented here fit well with other studies suggesting that percent crude protein of orchardgrass increases when grown in the shade. This may be due to slower maturity of orchardgrass grown in silvopastures when compared to open pastures. Higher crude protein during the beginning of the season may be an added benefit in silvopasture systems as farmers could reserve them until periods of summer heat. During this time they would not risk lowering forage quality when compared to open pastures. Statistically similar crude protein content during the August sample may be related to the low sample size (3) or be a factor of soil nutrient availability during the latter part of the summer. Similar ADF and NDF concentrations between silvopastures and open pastures suggest that digestibility of orchardgrass was not affected by the presence of trees.

Shade has been shown to significantly increase the nutritional quality of forages. Specifically, an increase in tree density has been found to be associated with an increase in crude protein concentrations in forages (Buergler et al., 2006). In one central Appalachian study, the quality of orchardgrass grown under a shade was better than that grown in full sun (Belesky et al., 2006). Specifically, the crude protein percent of orchardgrass grown in a woodland setting was significantly greater in two canopy cover treatments (18% and 32%) than that grown in full sun conditions (13% and 20%), although total non-structural carbohydrates were lower in concentration under woodland grown samples, reducing digestibility (Belesky et al., 2006). Crude protein percent of a tall fescue (*Festuca arundinacea*)/orchardgrass mixture under shade when compared to full sun was also found to be higher in an Arkansas alley cropping study, 17.2% and 14.1% respectively (Burner, 2003). These values were similar to that of another study which found the percent crude protein of orchardgrass to be significantly less between that grown in the open (17.6%) and that grown under trees at 60% of full sun (20.1%) (Varella et al., 2001).

In a follow-up analysis to the Lin et al (1999) study on shade effects to forages, the nutrient content of forages were compared between full sun, 50% shade, and 80% shade grown plants (Lin et al., 2001). Total crude protein of orchardgrass in their study was similar for variety ‘Justus’ between treatments but increased significantly with shade for variety ‘Benchmark’ (Lin et al., 2001). The acid detergent fiber (ADF) and neutral detergent fiber (NDF) of orchard grass was statistically similar for orchardgrass under all light conditions, with the exception of ‘Benchmark’ having significantly less ADF when grown under 80% shade (Lin et al., 2001). This suggests that the digestibility of orchardgrass remained consistent as shade was manipulated, a contrast to the results of Belesky et al (2006). In a similar study to Lin et al (2001) the NDF of orchardgrass was similar between grasses grown in full sun and 55% shade but reduced under 80% shade, while ADF fiber significantly increased in orchardgrass with shade (Huck et al., 2001). These results would seem mixed in terms of digestibility, but neutral detergent fiber insitu (NDFIS) was statistically similar for orchardgrass grown under all shade conditions, suggesting no change in digestibility with shade (Huck et al., 2001).

The early heading nature of orchardgrass causes it to lose crude protein faster than other forages (Casler and Kallenbach, 2007) therefore grazing management should aim to capture its early growth to maximize nutrition over time. However based on these results this need may be delayed longer in a silvopasture than an open pasture. Nitrogen deprivation can reduce the ability of grasses to form amino acids and thus protein synthesis. Symptoms of severe nitrogen deprivation were witnessed on the research site in orchardgrass during year 1, these symptoms being leaf yellowing and browning of sward tips (Snyder and Leep, 2007). Nitrogen fertilization is likely needed on the site to optimize orchardgrass performance and nutrition.

Tree growth and stem quality

The lack of epicormic branching in the post-treatment inventories on silvopastures and open pastures is likely a result of the silvicultural treatment utilized. In a low thinning, stems are removed from the lower diameter classes, leaving dominant and co-dominant stems as residuals. This site pre-treatment was a pole-sized stand going through the last stages of stem exclusion, meaning tree crowns were beginning to diverge in the canopy. The low thinning may not have exposed residual trees to excess stress or sunlight as these trees were already in dominant and exposed positions within the stand. This may also be the reason for the lack of windthrow on the site as residual stems may have experienced little increase in wind stress after the removal of shorter stems.

More importantly, two growing seasons is a relatively short time to monitor tree growth and health. The effects of harvesting and main treatments may not be realized on this site for an additional 3-5 years as any stressed trees run out of stored energy reserves. Therefore, while preliminary data suggest no difference in stem quality, mortality, and growth between silvopastures and woodlot treatments, long-term monitoring is needed to draw any conclusions about these factors. This is especially true as the silvopasture sites have only witnessed three rounds of grazing thus far; totaling 6 days between each plot over two years.

Financial Analysis

Silvopasture and no management were competitive in terms of IRR and NPV in this financial analysis, and both outperformed open pasture and woodlot treatment expected returns when initial timber harvesting costs were incorporated. The initial costs to convert a site to silvopasture or even a thinned woodlot are incredibly important in how an investment will be realized. In this case, initial timber harvesting costs were high due to research needs, a small treatment area, and the removal of only small stems. In northern hardwood ecosystems precommercial thinnings are often not financially viable due to their high up-front costs and long term nature of their returns. In this situation, the annual revenue from forage in silvopastures buffered the upfront timber harvesting costs. However, profit through silvopasture could have been improved if a larger area were converted, lowering the per unit area cost. For example, a similar, but profitable, biomass harvest was conducted on the same farm later that year but the 4 hectares (10acres) harvested were combined with a different landowner's 24 hectare (60acre) harvest operation. Economies of scale must be considered when analyzing the initial timber harvesting portion of silvopasture establishment.

Regardless of initial timber harvesting cost inclusion, silvopasture outperformed open pasture in terms of both IRR and NPV. The only treatment which performed better than silvopasture in terms of IRR was no-management when silvopasture initial harvesting costs were taken into consideration. This is logical because in the no-management situation there are no establishment costs and high yield when mature timber is harvested in 30 years. However, the silvopasture treatment outperformed no-management at NPVs with discount rates of 3%, 4%, and 5%. Silvopasture systems are known to be relatively robust to changes in discount rates and conditions due to the long-term and short-term of revenues (Ares et al., 2006; Broughton et al., 2012). Systems with high establishment costs and long periods before revenue streams will not compete well with systems with low establishment costs and annual revenue streams, especially at high discount rates. This is why no management was competitive with silvopastures when initial timber harvesting costs were accounted for.

Forestland owners who are considering the conversion of forests into silvopastures need to take into consideration the current condition of their forests and the opportunities for establishment. This study was limited by a single forest starting condition and a single residual tree density. Forests with financially mature sawtimber may not benefit as much from the low-thinning utilized here. In mature forests it may make more financial sense to regenerate a new stand while establishing a silvopasture, as mature trees are likely to have peaked in terms of timber value. The tradeoff would have to be assessed between protecting regeneration from livestock and long-term production of future crop trees. Additionally, no costs for management of invasive alien plants were included in this study as none were found on the site. In many areas of the Northeastern United States, opening up a forest canopy will release advance regeneration of invasive alien plants adding an upfront vegetation management cost that may be prohibitive to silvopasture establishment. In summary, this financial analysis supports the financial viability of hardwood silvopastures suggested by past research (Garrett et al., 2004). However, the costs and benefits utilized in this study are specific to local conditions, and while they may inform future silvopasture development, they should not be assumed applicable to all sites and forest management conditions.

Another shortcoming to this analysis was excluding livestock values, even though livestock were only incorporated into each open and silvopasture plot for less than six total days over a two year period. The analysis not take into account any additional benefit toward livestock production that may be derived from a shaded/sheltered/climate controlled pasture. It is a fair assumption that livestock under heat or cold stress will have lesser yields, and this is backed by research which suggests that tree cover moderates temperature and that cattle yields increase under shelter (Ferrez et al., 2011; Kallenbach et al., 2009; McDaniel and Roark, 1956). What is not well understood is how much production will be increased by shelter from trees nor how this potential benefit is tied to variable climates. Therefore, while the shelter benefits from silvopasture may have real monetary yields in terms of livestock production, including them in this analysis would have added an unknown degree of variability when quantifying these benefits. More research needs to be conducted to quantify the financial benefits of shelter on livestock in silvopastures, and what percentage of farm pastureland should be maintained in silvopasture to capture these benefits over a grazing season.

This financial analysis did not take into account any differences of risk between silvopasture, open pasture, woodlot, and no management. Tree productivity in silvopastures is at potential risk to livestock damage but the degree of this risk and how it is mitigated by management techniques is understudied. Heavy thinnings of even-aged stands added additional risk of blowdown in the silvopasture and woodlot treatments. While no blowdown was observed on the site in the two years of this study, more time is needed to assess the degree of this risk. Favoring deep rooted and wind stable trees would lower the potential of blowdown in thinned forests. Price changes in timber over time were also not accounted for. In silvopastures and woodlots, tree species diversity was reduced, meaning they may be at a greater risk to price changes away from currently high valued timber species. The annual source of revenue from forage in silvopastures helps to buffer the risk of changes in values of standing timber.

CONCLUSIONS

Forage production in silvopastures is clearly competitive with that in open pastures on sites with a similar starting condition. Of the six forage establishment treatment groups tested, orchardgrass had the highest yields of dry matter. Future studies should not rule out other forages and species mixtures as potential silvopasture options. However, not planting forages, as was done in the control subplot treatment, does not lead to desirable cool season grasses. Additionally, planting forages in silvopastures in the first year after establishment treatments may be important as less desirable volunteer grasses will become more productive, and thus competitive, on the site during the second year. Silvopastures also show potential to hold nutritional quality of orchardgrass during the first part of the summer when compared to open pastures, an added value if silvopasture use is to be delayed until the heat stress periods of the summer. However, two growing seasons is a relatively short time to determine the long-term production of forages. Long-term research is needed to address the forage production potential and persistence in silvopastures when compared to open pastures.

Tree growth and stem quality did not differ during the first two years of establishment between silvopastures and similarly thinned woodlots. However, these are very short-term results on long-term crops and more time should be given to fully access any effects of silvopastures on tree growth. Financially, silvopastures perform well when compared to open pastures and thinned woodlot, but establishment costs are a major factor in the returns from these systems and any minimization of them will maximize profitability.

CHAPTER 3: ECOLOGICAL DYNAMICS DURING THE ESTABLISHMENT PHASE OF SILVOPASTURE, OPEN PASTURE, AND HEAVILY THINNED FOREST DURING THE FIRST TWO YEARS POST TREATMENT

ABSTRACT

The objective of this study was to investigate the understory plant and soil dynamics of forest conversion to pasture. To accomplish this, in 2012 a 50 year old northern hardwood forest in New York was converted to open pasture, silvopasture, and heavily thinned forestland. Following initial thinnings the two pasture treatments were seeded with forages and rotationally grazed with cattle. Forages were a split-plot treatment that included: none (a control treatment), loose hay depositing, orchardgrass (*Dactylis glomerata*)-white clover (*Trifolium repens*), perennial ryegrass (*Lolium perenne*)-white clover, Kentucky bluegrass (*Poa pratensis*)-white clover, and smooth bromegrass (*Bromus inermis*)-white clover. Understory plant inventories and soil sampling were conducted pre-treatment and 2 years post. This paper documents site dynamics during the first two years post-treatment. Understory non-woody plant richness increased across the site between 2012 and 2014 (F=73.633, P=<0.001), while species richness of understory woody plants remained statistically similar between years (F=2.648, P=0.150). Povertygrass (*Danthonia spicata*), bentgrasses (*Agrostis spp*), buttercup (*Ranunculus* spp), crabgrass (*Digitaria* spp), sheep sorrel (*Rumex acetosella*), and hawkweed (*Hieracium* spp) colonized all treatments during the two year period, while Jack-in-the-pulpit (*Arisaema triphyllum*), partridgeberry (*Mitchella repens*), and fall meadow-rue (*Thalictrum pubescens*) disappeared during the same time. Lowbush blueberry (*Vaccinium angustifolium*) disappeared from both silvopastures and open pastures during the two year period of management. Orchardgrass treatments in open pastures had the largest change in pH (0.31) followed by

orchardgrass in silvopastures, with a pH increase of 0.23. Bulk density significantly increased in open pastures and silvopastures by 2014 with respective values of 1.05g/cm^3 and 1.01g/cm^3. These groups were also significantly higher in bulk density than the forest group in 2014 (0.93g/cm^3) but stayed statistically similar to each other. Soil organic matter was not found to be significantly different between years, main treatment or forage treatment. Percent total N, PMN, and P increased in silvopastures, open pastures, and woodlot treatment groups. Future research should investigate the functional mechanisms behind ecosystem changes when converting forestland to pasture.

INTRODUCTION

Silvopasture, the sustainable integration of livestock, forage, and trees on the same unit of land has been considered a conservation mechanism in many areas of the world. Two documented ecological benefits of successful silvopasture systems include carbon storage and increased fertility of degraded ecosystems (Clason and Sharrow, 2000; Garrett et al., 2004; Howlett et al., 2011b). However, little is known regarding the ecological characteristics of silvopastures created from hardwood forests or how this practice compares to other options for the same unit of land, such creating an open pasture or managing the land as a forest. This research investigated the understory plant and soil dynamics of forest conversion to silvopasture, open pasture, and a heavily thinned forest without cattle.

Silvopastures are managed agricultural systems and must be carefully planned to maximize efficiency while minimizing detrimental ecological externalities. While silvopasture has been found to have numerous conservation benefits, too often these benefits are based on silvopasture comparison with treeless agricultural systems (Clason and Sharrow, 2000; Garrett et al., 2004). Whether or not silvopasture is a conservation mechanism likely depends on what it is being compared to. Past research specific to hardwood silvopastures has discussed only the potential benefits of silvopasture (Chedzoy and Smallidge, 2011b; Garrett et al., 2004). It is important that both the conservation benefits and tradeoffs of agricultural practices be discussed in scientific literature so policy makers and practitioners are able to responsibly weigh the environmental impact of a practice. From a practical standpoint, it is important to understand the ecological dynamics of silvopasture establishment from hardwood forests in order to optimize any conservation mechanisms.

Trees in agroforestry systems play a functional role in nutrient cycling by mining nutrients from subsurface soil layers and depositing those nutrients on the soil surface through leaf and fine root senescence and crown abrasion. Trees also act to sequester carbon in an ecosystem which will persist in the soil fraction until it is slowly released through decomposition. Research from an oak silvopasture in Spain found that soil carbon stocks increased under tree canopies (Howlett et al., 2011b). The same researchers found that soil carbon was increased at deeper soil depths under silvopastures than open pastures, concluding that incorporating trees into agricultural landscapes will foster carbon sequestration (Howlett et al., 2011a). In a separate study occurring in a thinned loblolly-pine plantation in the Southern United States, soil carbon stocks were positively influenced by the establishment of grasses (Blazier et al., 2012). The combined effects of grass root exudates and tree litter have the potential to increase total soil carbon in silvopastures when compared to pastures without trees or forests without grasses. However, these dynamics are much understudied in silvopastures converted from forests. In an Appalachian hardwood study with silvopastures converted from forests, silvopastures and forests were found to have similar levels of woody contribution to soils, and more than an open pasture treatment (Gonzalez et al., 2010).

In terms of understory plant communities, no work has investigated changes in plant communities when converting forestland to pasture even though serious concerns about this practice have been expressed by some conservation organizations (Arbuckle, 2009). Some work has been conducted comparing plant composition between established silvopastures and open pastures. A study in Georgia compared the understory forage community of a young longleaf pine (*Pinus palustris* Mill.) silvopasture with that in an open pasture (Karki et al., 2013). Results indicate that plant community composition differed between silvopastures and open pastures (Karki et al., 2013). In Europe, the long-term influence of grazing by livestock in woodlands has led to plant communities that would readily shift in the absence of livestock (Rigueiro-Rodriguez et al., 2009). Repeated grazing, and competition from seeded forages, is likely to alter the understory plant communities of pastures and silvopastures when compared to forests not exposed to these factors.

One criticism of forest conversion to silvopasture as a conservation mechanism is the potential for initial losses of soil nutrients due to intensive tree removal and ground scarification. The importance of maintaining vegetative cover on a site after heavy timber harvesting was demonstrated in two clearcut whole tree harvested stands at the Hubbard Brook research forest in New Hampshire. In this comparison one stand was clearcut while the other was clearcut and received herbicide treatments. The stand which received herbicide treatments yielded nearly three times the water to streams than the clearcut stand, suggesting increased nutrient leaching as well (Campbell et al., 2007). No research has investigated nutrient dynamics and site revegetation potential in forests converted to silvopasture or open pasture.

Livestock pose another challenge to the conservation argument for forests converted to silvopastures. Livestock excretion has been found to be a significant source for nutrient losses from system nutrient pools in open pastures (Sharpley and West, 2008). In silvopasture systems the combined effects of forage and tree root systems has been found to function as a nutrient capture mechanism (Bambo et al., 2009; Blazier et al., 2008).

The objective of this study was to investigate the understory plant and soil dynamics of forest conversion to pasture. To accomplish this a 50 year old northern hardwood forest in New York was converted to open pasture, silvopasture, and heavily thinned forestland. This paper documents site dynamics during the first two years post treatment. We hypothesized that understory plant diversity and soil properties would begin to diverge between silvopasture, open pasture, and thinned forest treatment groups. We expected that the retention of trees would mitigate soil and understory plant changes resulting from timber harvesting and livestock grazing. Understory plant diversity and soil property divergence from pre-treatment conditions were expected to be greatest in open pastures, followed by silvopastures and thinned forestland.

METHODS

Site

This research took place on North Branch Farm, located in the town of Saranac, New York, part of the Adirondack Mountain region. Prior to manipulation of the 2.7 hectare (6.75 acre) site for this experiment the area was a 50 year old mid-succession northern hardwood forest with an average soil pH of 4.68. Species composition was dominated by pole size northern hardwoods including red maple (*Acer rubrum*), paper birch (*Betula papyrifera*), white ash (*Fraxinus Americana*), black cherry (*Prunus serotina*), aspen (*Populus* spp.), American elm (*Ulmus Americana*), apple (*Malus* spp.), and American basswood (*Tilia Americana*). Overstory basal area averaged 19 m^2/ha (83ft^2/ac) and was comprised of 2434 stems/ha (985 stems/ac) with a quadratic mean diameter of 9.9cm (2.9in) (Table 1). Important to note is that no invasive alien plants were found during pre or post treatment inventories, potentially making this site different than more urban forests in the Northeastern United States. The pre-treatment understory plant community was dominated by *Rhubus* spp, *Solidago* spp, and other herbaceous forest plants typical of northern hardwood forests. Extremely few grass species were present on the site pre-treatment. The site's history includes charcoal production in the 1800's followed by cattle pasture until the 1960's when use ceased and the site gradually reverted back to forest.

TABLE 1: Overstory conditions in silvopasture and woodlot treatments pre-treatment in 2012 and in 2014 two years after a low thinning. Silvopasture treatments were seeded with forages and grazed with cattle between 2012 and 2014. Inventories were conducted at the same plot centers using fixed area plots in systematic random design. Means are reported with (standard errors). Relative density was calculated using NED2 (Twery et al., 2005). n = 36.

Measure	*Pretreatment 2012*	*Post Treatment 2012*	*Post Treatment 2014*
Basal Area/Ha (m^2)	19 (1)	6 (1)	7 (1)
Trees/Ha	2434 (124)	531 (94)	558 (100)
Quadratic Mean Diameter (cm)	9.9	12	12.3
Volume (m^3 ha^{-1})	68 (9)	25 (7)	29 (7)
Relative Density	78% (3%)	21% (3%)	23% (3%)
Photosynthetically Active Radiation (% of full sun)	7.8 (1.3)	21% (3%)	53.1 (5.4)

Experimental Design

The experimental design was a split-plot randomized complete block (Figure 1). The main plot factor (Table 2) was overstory conditions and there were three treatments: heavy thinning favoring crop trees (forest), silvopasture, and open pasture (all trees removed). Each main plot treatment was replicated three times using 1/3 hectare plots. The locations of these plots were randomized within each of the three blocks. The forest treatment allowed a comparison of silvopasture understory plant and soil dynamics to that of a forest without cattle and planted forages. The open treatment allowed a comparison of silvopasture understory plant and soil dynamics with a newly established open pasture. Response variables for the main plots included understory plant species richness and diversity, and soil physical and nutrient properties.

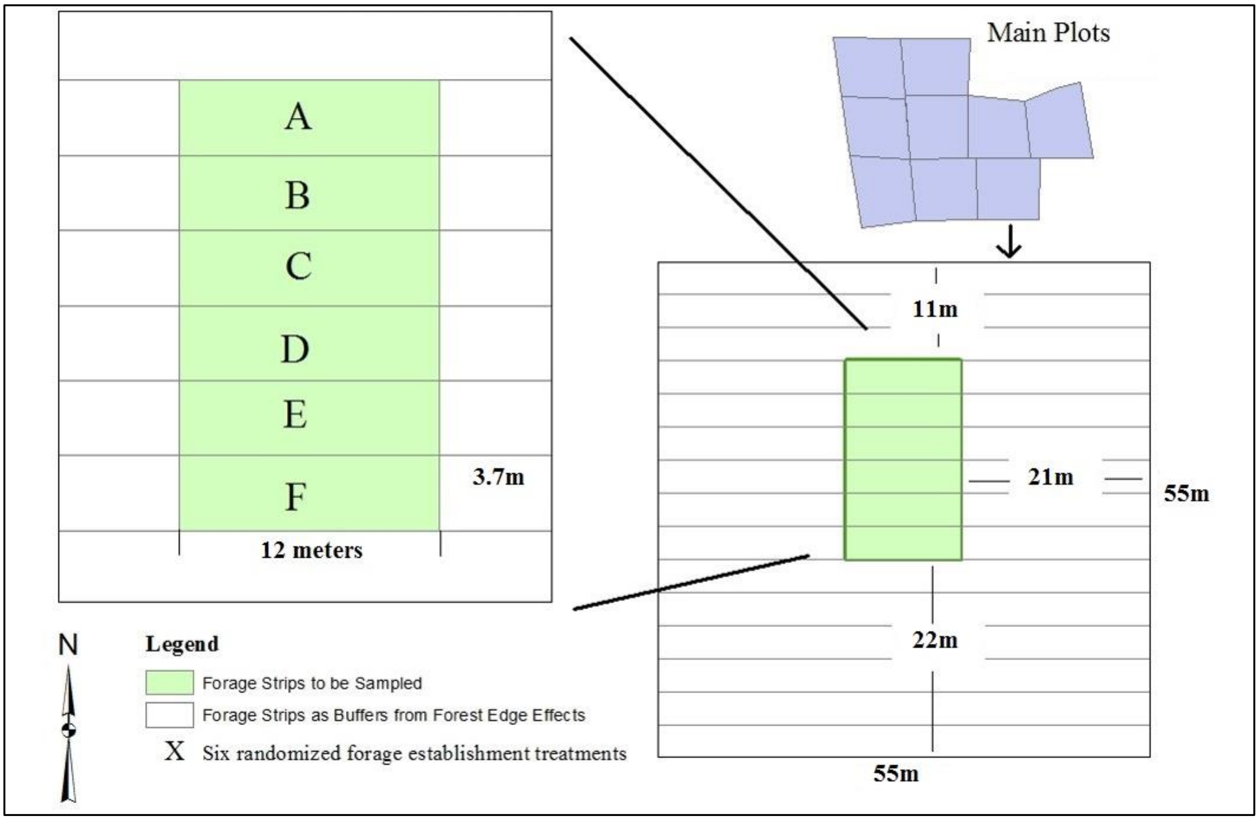

FIGURE 1: Split-plot design of forage establishment treatments in silvopasture and open plots. Sampling of forages occurred in five fixed locations the centers of each strip. No forages were sampled in the buffer zone.

Main plot treatments were established in July of 2012. The forest and silvopasture treatments had the forest overstory basal area reduced to 32% of pre-harvest basal area, a level slightly less than stocking levels on silvopastures in other regions (Devkota et al., 2001; Garrett et al., 2004; Walter et al., 2007). Dominant and well-formed stems were favored in a uniform spacing heavy low thinning. Black cherry and red maple comprised the majority of stems favored with white ash and American elm were selected against. Black cherry's timber value dictated its retention even though its leaves can be toxic to livestock when wilted. In open treatments, 100% of trees were removed. Trees were thinned in the woodlot treatment to ensure consistent tree density, and thus similar crown competition, between it and the silvopasture treatment. A no-treatment group was not included because of available land limitations and a desire to maintain similar light dynamics in the overstory and understory between woodlot and silvopasture treatments. During the course of the first week of July 2012, a logging contractor was hired to harvest the site using whole-tree felling and skidding techniques. Harvested trees were chipped off-site and sold by the logging contractor for biomass, 64 metric tons/ha of chips (29 tons/ac) were removed and an inventory based estimate of 18 metric tons/ha (8 tons/ac) remained on the site between silvopasture and woodlot treatments.

TABLE 2: Main treatment comparisons between woodlots, silvopastures, and open pastures. Initial harvesting and seeding took place in 2012 and grazing occurred in silvopasture and open pasture treatments in 2013 and 2014.

Treatment	*Silvicultural Prescription*	*Harvest Type*	*Forages*	*Cattle*
Woodlot	Heavy Low Thinning	Mechanical, whole tree removal	No Treatment	Excluded
Silvopasture	Heavy Low Thinning	Mechanical, whole tree removal	Seeded	Grazed
Open Pasture	Clearcut	Mechanical, whole tree removal	Seeded	Grazed

The split-plot factor in this experiment was forage establishment (Figure 1). Forage treatments were established in the silvopasture and open pasture main plot treatments. The forage establishment treatments included: none (a control treatment), loose hay depositing, orchardgrass (*Dactylis glomerata*)-white clover (*Trifolium repens*), perennial ryegrass (*Lolium perenne*)-white clover, Kentucky bluegrass (*Poa pratensis*)-white clover, and smooth bromegrass (*Bromus inermis*)-white clover. Forages were broadcast seeded in silvopasture and open pasture treatment groups using a hand operated seeder on August 15th and 16th of 2012. The seeder was calibrated off-site for each species prior to on-site use. The loose hay treatment utilized locally-sourced hay bales spread thinly to simulate on-pasture feeding of livestock. High quality, first cut, timothy (*Phleum pretense*) hay with seed heads was selected to ensuring a quality and weed free seed source. White clover was seeded at a rate of 5.6kg pure live seed per hectare (5lbs/ac). Grasses were broadcast seeded at rates of 22.4 kg pure live seed per hectare (20lbs/ac). Immediately following seeding, cattle, 2,222.6kg (4,900lb) herd weight, were let in to all open pasture and silvopasture plots for one day to trample in seed.

In 2013 and 2014 all silvopasture and open treatments were grazed with beef cattle to a forage height of 5cm (2 inches). Grazing intensity was similar between plots and no preferential grazing of forage treatments by cattle was observed. In August 2013 dry matter forage availability of grasses and legumes averaged 409 kg/ha in open pastures and 255 kg/ha in silvopastures. Dry matter forage availability averaged 314 kg/ha in open pastures and 187 kg/ha in silvopastures during June 2014; forage availability in August 2014 was 266 kg/ha in open pastures and 228 kg/ha in silvopastures. Other non-woody and woody plants were also available on the site for cattle consumption during each grazing period. The first round of grazing took place in August of 2013. Each 1/3 hectare silvopasture and open plot were grazed by cattle, herd weight of 4,264kg (9,400lbs), for two consecutive days. During the first week of June 2014 and the middle of August 2014 a cattle herd weight of 5,443kg (12,000lbs) was grazed on each silvopasture and open plot for two and 1.5 days, respectively.

Data Collection and Analysis

In May and July of 2012, prior to any treatments on the site, an inventory of all trees over 1.3cm (0.5in) diameter at breast height (DBH) and ground cover flora was conducted. 1/50th hectare (1/20th acre) inventory plots were established for a tree and shrub inventory. Tree species and DBH were recorded for each tree or shrub. Understory plants were sampled using $2m^2$ ($21.5ft^2$) fixed area plots nested on overstory plot centers and a count tally of individuals in each species or genera was recorded. Plots were located in a systematic random manner away from main plot edges. Four overstory and four understory plots comprised the inventory for each main treatment plot, totaling 36 total plots. The tree and understory plant inventory was repeated in the same locations post treatment in 2012 and during the summer of 2014 to address changes in each treatment.

Soil samples were collected within each forage treatment strip in the center portions of the main plots to minimize potential edge effects (Figure 1). The edge buffer was narrower on the north side of main plots due to the southern aspect of the site and forest canopy light dynamics related to the sun's location in the northern hemisphere. Soil samples were an aggregate of five subsamples distributed evenly through the center of each strip and collected to a depth of 10cm (3.9in). Soil samples were collected at the same locations in the pre-treatment inventory of July of 2012 and the post-treatment inventory of July of 2014. With the exception of bulk density samples, which were analyzed at the Adirondack Watershed Institute, soil samples were sent to the Cornell Nutrient Analysis Laboratory in Ithaca, NY and analyzed for pH, extractable bases through the Mehlich-III extraction, organic matter through loss on ignition, total C and N, and potentially minerizable nitrogen (PMN).

All statistical analysis were performed using R (R Core Team, 2014). For understory plants, species richness and Shannon-Wiener Diversity Index of each main treatment plot was calculated. The results of these measures were then analyzed between treatment groups and years using ANOVA. A split-plot ANOVA model was used to test for significant differences in soil properties between main treatments, year, and forage strips. Additionally, the degree of change of soil measure at each soil sampling location was analyzed using a split-plot ANOVA for main treatment and forage treatment effects. This reduced the risk of any starting differences between each treatment group showing up as treatment effects through a covariance. To avoid type II error, the alpha used for indicating significance between treatments was 0.1. Pairwise comparisons were made using the Least Significant Difference method.

RESULTS

Understory Plants

Understory non-woody plant richness increased across the site in the two years post-treatment (F=73.633, P=<0.001), while species richness of understory woody plants remained statistically similar between inventory years (F=2.648, P=0.150); Table 3. No treatment or interaction effects were found between main treatment groups for species richness of woody understory plants. Main treatment did have a significant effect on richness of non-woody understory plants (F=6.015, P=0.037). Pairwise comparisons of main plots pre-treatment (2012) indicated that richness of non-woody plants was significantly higher in the silvopasture treatment group than in forest treatment group; with the open pasture group not being significantly different from either of the other two groups. Post-treatment (2014), silvopastures had significantly higher species richness of non-woody plants than open pastures or forest treatment groups (Table 3).

An interaction between treatment and year was found for the Shannon-Wiener Diversity index for non-woody understory plants (F=3.741, P=0.088). Overall, diversity of the site was low, ranging from 1.39 for open pastures in 2012 to 2.13 for forests two years post-treatment (Table 3). The silvopasture treatment group had significantly higher diversity than open pasture or forest treatment groups prior to treatment in 2012. No significant differences of diversity were found between treatment groups post-treatment in 2014. The diversity of open pasture and woodlot treatment groups significantly increased from their respective pre-treatment diversity values (1.39 and 1.45) to their post-treatment diversity values (2.12 and 2.13). Silvopasture saw no significant change in diversity with a pre-treatment value of 1.86 and post-treatment value of 2.03. No significant differences were found between Shannon-Wiener diversity for woody understory plants between years (F=0.014, P=0.909) or main treatments (F=0.852, P=0.427). The lowest diversity of woody understory plants by this measure was 1.03 for open pastures post-treatment and the highest was 1.70 for silvopastures post-treatment (Table 3).

TABLE 3: Understory Plant Diversity 2012 and 2014, n = 3. Non-woody species were grouped by genus for richness and Shannon-Wiener diversity calculations. Data are means. Within a row, means sharing the same letter are not different at the P < 0.1 level (LSD means test)

	Pre-Treatment (2012)*			Post-Treatment (2014)*			ANOVA		
Measure	FO	SP	OP	FO	SP	OP	Treatment (T)	Year (Y)	T x Y
Non-Woody Plants								*P > F*	
Richness	13.67e	17.00cd	14.67de	18.33bc	22.67a	20.00b	0.037	0.001	NS
Shannon-Wiener	1.45b	1.86a	1.39b	2.13a	2.03a	2.12a	0.724	0.001	0.088
Woody Plants									
Richness	8.00	7.00	6.67	9.67	7.00	4.00	NS	NS	NS
Shannon-Wiener	1.46	1.49	1.46	1.61	1.70	1.03	NS	NS	NS

*Abbreviations are FO, thinned forest; SP, silvopasture; OP, open pasture

Trout lily (*Erythronium americanum*), *Solidago* spp, *Rhubus spp*, and *Carex* spp were consistently in the top ten most abundant understory plants across the all treatment groups in pre and post-treatment inventories. Jack-in-the-pulpit (*Arisaema triphyllum*), partridgeberry (*Mitchella repens*), and fall meadow-rue (*Thalictrum pubescens*) were all present in the 2012 pre-treatment inventory but absent in the 2014 post-treatment inventory. Povertygrass (*Danthonia spicata*), bentgrasses (*Agrostis spp*), buttercup (*Ranunculus* spp), crabgrass (*Digitaria* spp), sheep sorrel (*Rumex acetosella*), and hawkweed (*Hieracium* spp) were present in post-treatment but absent pre-treatment for all treatment groups. Planted forages of bluegrass, smooth bromegrass, orchardgrass, perennial ryegrass, and white clover were present in the post-treatment inventory but absent in the pre-treatment inventory within silvopasture and open pasture treatment groups. No planted grasses were found in the pre or post-treatment inventories of the forest treatment group. Lowbush blueberry (*Vaccinium angustifolium*) was present in all treatment groups during the pre-treatment inventory but absent from the open pasture and silvopasture treatment groups in the post-treatment inventory. No invasive alien plant species were found on the site in either inventory.

Soil pH

No significant changes in soil pH were found for main treatment (F=1.781, P=0.247) or years (F=1.596, P=0.210) per or post-treatment (Table 4). The change in pH was highest in the forest treatment group with a change of -0.15 while silvopasture and open pasture treatment groups had pH changes of 0.00 and 0.02 respectively, but this trend was not statistically significant (F=1.643, P=0.270). Soil pH was found to differ between forage treatments in silvopasture and open pasture treatment groups (F=2.140, P=0.078). Pairwise comparisons indicate that the orchardgrass treatment group had significantly higher pH (4.82) than the bluegrass (4.63) and control (4.57) treatment groups. Smooth bromegrass, perennial ryegrass, and hay treatment groups were not significantly different from any other group and had respective pH values of 4.72, 4.72, and 4.69. Similar results were found when change in pH between 2012 and 2014 was analyzed for forage treatment groups in silvopastures and open pastures. A significant interaction between main treatments and forage treatments was found for change in pH between years (F=2.399, P=0.074). LSD analysis of group means indicated that orchardgrass treatments in open pastures had the largest change in pH (0.31) followed by orchardgrass in silvopastures, with a pH increase of 0.23. These were both significantly higher than pH changes in the open pasture hay (-0.11), open pasture bluegrass (-0.19), silvopasture ryegrass (-0.22), and silvopasture control (-0.26) treatment groups. Figure 2 displays these changes graphically.

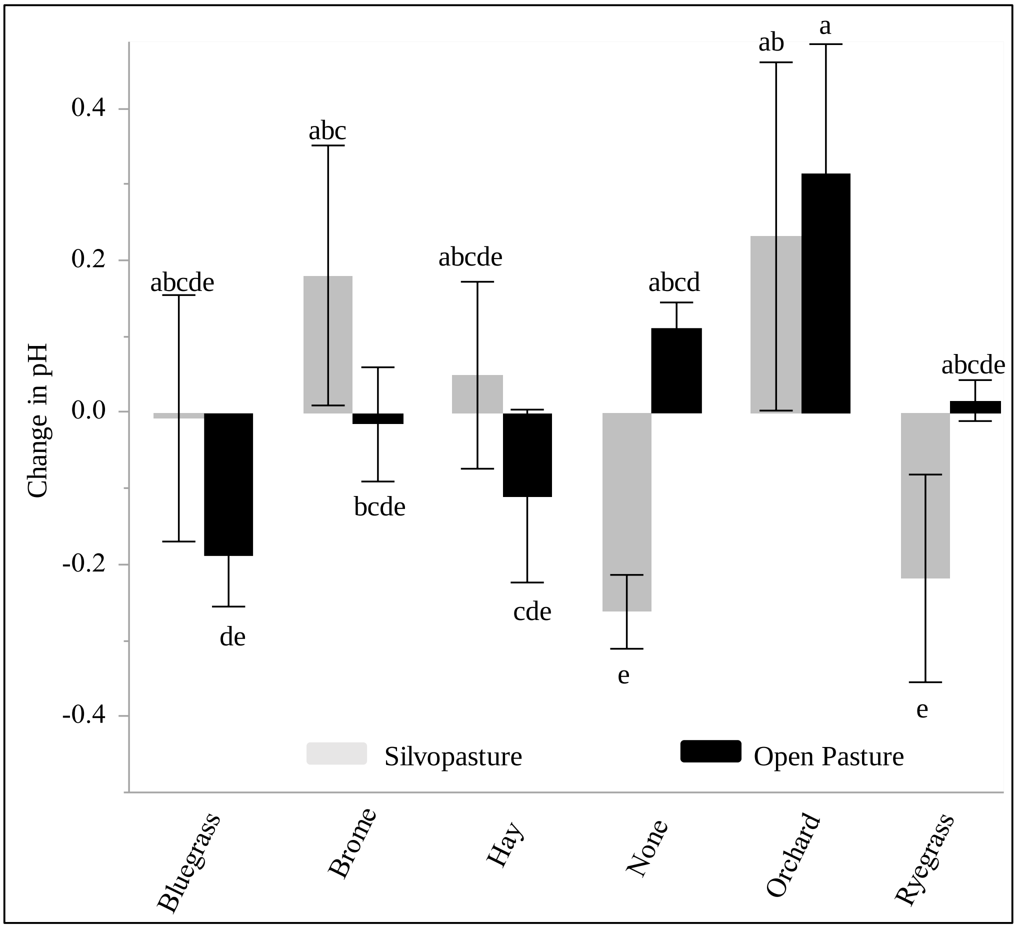

FIGURE 2: Change in soil pH two years post-treatment among forage treatments in silvopastures and open pastures created from a forest. Six forage treatments were established in a split-plot design: bluegrass/white clover, smooth bromegrass/white clover, loose hay depositing, no forages planted, orchardgrass/white clover, and perennial ryegrass/white clover. Soils were sampled pre-treatment of the site in 2012 and resampled in the same locations two years post treatment in 2014. Note the increase in pH of orchardgrass strips in both silvopastures and open pastures. Values are means and error bars are standard error. Shared letters indicate no significant difference between means. n=3.

Soil Bulk Density

A significant interaction was found between main treatment and year (F=2.884, P=0.061) for soil bulk density. Pairwise comparisons reveal that bulk density values were similar between forest (0.90g/cm^3), open pasture (0.92g/cm^3), and silvopasture (0.94g/cm^3) groups in the 2012 pre-treatment inventory. However, bulk density in open pastures and silvopastures significantly increased over the two years with respective values of 1.05g/cm^3 and 1.01g/cm^3. Open pasture and silvopasture groups were also significantly higher in bulk density than the forest group post-treatment (0.93g/cm^3) but stayed statistically similar to each other. The forest group did not see a significant increase in bulk density between 2012 and 2014 (Table 4).

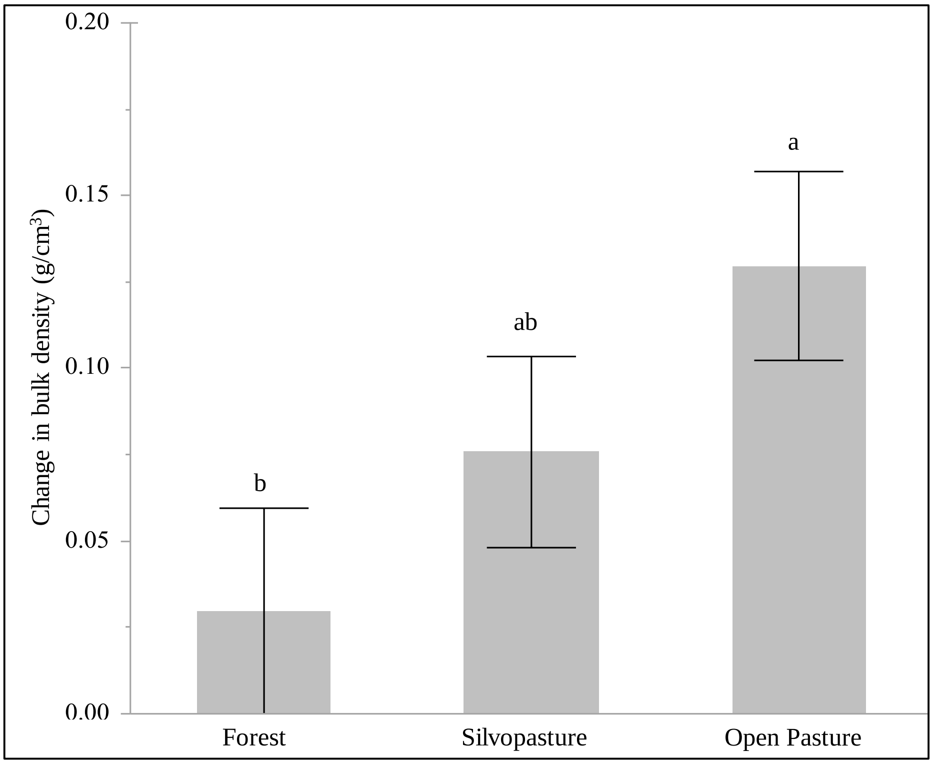

FIGURE 3: Change in soil bulk density on sandy soils of thinned forests, silvopastures, and open pastures created from forestland in 2012. Sampling was conducted pre-treatment in 2012 and two years post-treatment in 2014. Bulk density increase across the site is attributed to timber harvesting equipment. Bulk density increase in silvopastures and open pastures is attributed to livestock grazing in 2013 and 2014. Trees in silvopastures are acting to bugger against soil compaction due to livestock. Shared letters indicate no significant difference between means. n=3.

Table 4: Soil property changes in three forest conversion treatments. Samples were collected in the upper 10cm of soil. Data are means. Within a row, means sharing the same letter are not different at the $P < 0.1$ level (LSD means test).

	Pre-Treatment (2012)*			Post-Treatment (2014)*			Change (2012-2014)*			ANOVA		
Soil Property	FO	SP	OP	FO	SP	OP	FO	SP	OP	Treatment (T)	Year (Y)	T x Y
											$P > F$	
pH	4.67	4.63	4.74	4.51	4.63	4.77	-0.15	0.00	0.02	NS	NS	NS
Bulk Density (g cm^{-1})	0.90b	0.94b	0.92b	0.93b	1.01a	1.05a	0.03b	0.08ab	0.13a	NS	<0.001	0.061
Organic Matter LOI (%)	7.35	7.30	7.20	7.85	6.86	6.61	0.42	-0.31	-0.41	NS	NS	NS
Total C (%)	3.18b	3.75ab	3.34b	4.05a	3.66ab	3.35b	0.87	-0.09	0.01	NS	NS	0.055
Total N (%)	0.12e	0.21cd	0.18d	0.26ab	0.27a	0.23bc	0.14	0.06	0.05	NS	<0.001	0.001
PMN (mg kg^{-1})	27.53bc	16.35c	16.53c	87.72a	76.41a	45.28b	60.19	60.06	28.74	NS	<0.001	0.098
Ca (mg kg^{-1})	374.81	462.01	454.84	385.62	370.20	377.53	10.81	-91.81	-77.31	NS	0.069	NS
K (mg kg^{-1})	54.49abc	61.97a	56.32ab	42.71c	45.87bc	62.13a	-11.78	-16.10	5.81	NS	0.063	0.058
Mg (mg kg^{-1})	42.46b	57.92a	57.77a	56.18a	53.98ab	50.67ab	13.72	-3.94	-7.10	NS	NS	0.03
P (mg kg^{-1})	9.10	4.80	7.68	17.16	10.32	14.60	8.05	5.52	6.92	NS	<0.001	0.464

*Abbreviations are FO, thinned forest; SP, silvopasture; OP, open pasture

A main treatment effect was found for bulk density change between pre and two years post-treatment (F=5.177, P=0.049). LSD analysis indicated that open pastures saw the greatest increase in bulk density (0.13g/cm^3) and this change was significantly greater than the bulk density change incurred in the forest group (0.03g/cm^3). Bulk density increases in the silvopasture group (0.08g/cm^3) was not significantly different from either of the other two groups (Figure 3). No significant relationship was found between forage treatment and bulk density.

Soil nutrients

Soil organic matter was not found to be significantly different between years, main treatment or forage treatment, Table 4. However, a significant interaction was found between years and treatment for percent total C in soils (F=2.995, P=0.055). Pairwise comparisons show no significant differences in percent total C between main treatments during the pre-treatment inventory but a significantly greater percent total carbon in the forest group (4.05%) than in the open treatment group (3.35%) two years post-treatment. Percent total C in the silvopasture group (3.66%) was not significantly different from either the open or forest groups. The change in percent total carbon was not significantly different between silvopasture (-0.09%), open pasture (0.01%), or forest (0.87) treatment groups (F=1.155, P=0.376).

Percent total N increased in all main treatment groups between 2012 and 2014. Percent total N had a significant interaction between year and main treatment (F=7.974, P=<0.001) but no significant differences for degree of change or forage treatment. Main treatment pairwise comparisons indicated that the forest group was significantly lower in percent total N than silvopastures post-post treatment (Table 4). However, post-treatment percent total N in the forest group (0.26%) was not statistically different from silvopasture (0.27%) or open pasture

(0.23%) groups. While statistically similar to open pastures pre-treatment, silvopasture had a significantly higher percent total N than open pastures two years post-treatment (Table 4).

Similar to percent total N, an interaction was found between main treatment and year for PMN (F=2.383, P=0.098). Pre-treatment open (16.53 mg/kg), forest (27.53 mg/kg) and silvopasture (16.35 mg/kg) groups all had statistically similar concentrations of PMN. Post-treatment silvopasture (76.41 mg/kg) and forest (87.72 mg/kg) PMN concentrations were similar to each other, but significantly higher than open pasture (45.28 mg/kg) concentrations.

Soil Ca and P concentrations changed on the site between pre and post-treatment. Ca significantly decreased on the site over the two years (F=3.382, P=0.069), while P significantly increased (F=67.327, P=<0.001). No main treatment or forage effects were found for Ca or P.

Mg (F=3.651, P=0.030) and K (F=2.937, P=0.058) both had a significant interaction between main treatment and year. Mg concentrations were lower in the forest group pre-treatment but similar between open pasture and silvopasture groups. Post-treatment Mg concentrations were similar between all main treatment groups. While change in Mg concentration trended from positive in the forest group (13.72 mg/kg) to negative in the silvopasture (-3.94 mg/kg) and open pasture groups (-7.10 mg/kg), these means were not significantly different (F=1.055, P=0.405). K concentrations were similar between main treatments pre-treatment but were significantly greater in the open pasture group than the forest or silvopasture groups two years post-treatment (Table 4).

DISCUSSION

Understory Plants

Understory plant richness and diversity are indicators of changes in forest conditions. Here they were used to measure divergence of community structure from an undisturbed forest ecosystem after three different approaches to management. Species richness, although statistically different, was similar by order of magnitude between main treatments and thus could be considered fairly minimal. Increases in richness, although small, are likely due to the effect of increased light resources and microsite availability post timber harvesting. Additionally, open pastures and silvopastures had a slightly higher species richness due to direct seeding of forages. The presence of bluegrass, smooth brome, orchardgrass, white clover, and perennial ryegrass in silvopasture and open treatments in the post-treatment inventory, coupled with their absence in the post-treatment forest group and on all treatments in the 2012 pre-treatment inventory, suggest they are the causes of increased species richness.

Diversity of understory non-woody plants across the site is low. This is likely due to many plants being identified to the genus, instead of species level. *Solidago* spp, *Rhubus* spp, and *Carex* spp were consistently in the top ten most abundant understory plants in pre and post-treatment inventories because they are highly adaptable forest edge and early successional plants. Trout lily's persistence on the site is unexpected because it is more typically found as an understory plant in forests. The corm nature of its growth, providing stored energy reserves, may be enabling trout lily's persistence on this heavily disturbed site. More time may be needed for trout lily to decrease in the pasture groups as foraging changes competitive plant interactions.

Forest plants showing greater sensitivity to disturbance than trout lily on the site included Jack-in-the-pulpit, partridgeberry, and fall meadow-rue. For these plants, either the disturbance physically harmed them or competitive dynamics post disturbance caused them to lose their hold on the site. The loss of these plants across all main treatment groups suggests that dynamics triggered by the initial disturbance from harvesting triggered led to their loss and not the incorporation of livestock or forages. The one exception to this is lowbush blueberry which disappeared from silvopasture and open pasture groups but not from forest groups in the post-treatment inventory. While tolerant of disturbed areas, lowbush blueberry loss from grazed treatments may have been due to browsing by cattle or competition with introduced forage grasses, which were not planted or found in the forest treatment group. Livestock induced changes in soil properties, such as increases in bulk density, may have also influenced the loss of lowbush blueberry in pastures. With the exception of lowbush blueberry, understory plant community richness and diversity indicate that main treatments had not significantly diverged during the first two years of management. The lack of differences in understory woody plant diversity is further evidence that plant communities in open pastures, silvopasture, and forest groups had not diverged during the establishment phase.

Important to note is that consumption of understory plants by cattle was not monitored during this study. Future work would do well to investigate the toxicity, palatability, and quality of forest and edge habitat plants in an effort to understand the competitive role livestock can play in forest conversion to pasture. This is especially important if livestock are to be used to manage understory plant community composition as very little work has been done on this subject (Belesky et al., 2007; Nunez-Hernandez et al., 1989; Turner and Foster, 2000; Welch, 1989). Additionally, some plants may be toxic or indigestible to livestock when certain concentrations are consumed (Kaitho et al., 1997). For example, *Rhubus* spp are not generally considered toxic to cattle but one study found that preferential grazing by pregnant cows on *Rubus spp*. lead to high rates of calf abortion; this was attributed to a high nitrate level in the genus (Sund et al., 1960). The amount, and timing, of consumption of potentially toxic plants is an important area to be addressed in future research. While no invasive alien plants were found in this study, the use of livestock as a tool to manage these plants in regional forests and silvopastures is being promoted (Chedzoy and Smallidge, 2011b), yet very little is known regarding their toxicity, palatability or nutritional quality for livestock.

Soils

The pH of forest soils is typically lower than what is desired for agricultural systems. It is not known to what degree soil pH will shift in response to forest conversion to pasture without soil amendments. Soil amendments are likely necessary additions to forest soils to maximize forage production when conversion to pasture occurs. From a conservation standpoint, reduction in soil amendments mitigates the risk of excess amendment leaching from a site. Past work comparing soil pH of forests, silvopastures, and open pastures found a trend between high pH in open pasture (6.8) when compared to silvopasture (5.5) and forests (4.7) in West Virginia (Staley et al., 2008). While these three groups occurred on similar soils they did not have similar management histories as the silvopasture was in its second year of development after conversion from the hardwood forest which was 60 years into stand development. The open pasture had been managed as such for about 40 years at the time of the study (Staley et al., 2008). Both the silvopasture and the open pasture had also received soil amendments, including periodic lime additions; the authors suggest this, and possibly less organic matter additions to soil because of consumption during grazing, as the reason for differences in pH between forests, open pastures, and silvopastures (Staley et al., 2008).

The results presented here suggest a similar low-high trend in pH may be starting to develop between forests, silvopastures, and open pastures even in the absence of soil amendments, but more time and future sampling will be necessary to determine if a statistically significant divergence occurs. An interesting finding from the pH results here is a relatively high increase in pH of orchardgrass treatments in both silvopastures and open pastures. As an example, an increase in pH of 0.23, as seen in the silvopasture orchardgrass group, is equivalent to adding 381kg/ha (340lbs/ac) of lime on the sandy soils in this study (de Long, 2004). The monetary value of purchasing this amount of lime based on local markets, application costs not included, is $92 per hectare. The pH change of orchardgrass treatments in silvopastures when compared to control treatments, where no forages were planted, was even greater with a pH disparity of 0.49. Forage species selection may be a means of indirectly increasing the soil pH of pasture systems, and thus reducing the need for soil amendments.

It is not likely that orchardgrass strips increased in pH due to less organic matter inputs to soil as a result of grazing as all forages were grazed to an even height. This was a suggested possibility by Staley et al. (2008) for increased pH in grazed areas compared to ungrazed forest in their study. The functional mechanism by which orchardgrass is increasing the pH of the soil is not within the scope of this study, but one possible cause may be a release of OH^- or HCO^- by orchardgrass to counterbalance uptake of HO_3^-. This relationship is a documented mechanism for which plant roots can increase the pH of the rhizosphere (Hinsinger et al., 2003). More research is clearly needed to investigate the pH dynamics of forest soils after conversion to pasture, especially regarding forage species selection. Do forest soils become less acidic in response to understory plant composition or grazing management regardless of soil amendments? If so, how long does it take, and what is the extent of change?

Soil bulk density results from this study provide support for the benefits of trees as a mitigation tool against soil compaction. While bulk density increased across the site, likely due to compaction from timber harvesting equipment, its greatest increase was in open pastures, followed by silvopastures, and lastly by forests (which saw no significant increase in bulk density). Based on previous work on coarse-textured soils, the bulk densities realized in this study would not inhibit the root growth of plants (Daddow and Warrington, 1983; Vepraskas, 1988). However, the functional role of living tree roots in buffering soil compaction caused by livestock is worth noting. Figure 3 shows the trend of bulk density increase between years for main treatments and it is clear that that livestock pressure was increasing soil compaction. Tree roots are likely the functional mechanism keeping compaction increases in silvopastures from being as high as those seen in the open pasture group, especially as livestock pressure was consistent between grazed treatments in this study. The benefit of tree roots in silvopastures to mitigate compaction from livestock might be most important during the establishment phase of pastures, when newly established forages are delicate and soils are at their highest risk to degradation from exposure and a temporary reduction in living plant roots. Results from Staley et al. (2008) indicate that the difference in bulk density between silvopastures and open pastures might endure in the systems over the long term. In their study, which occurred on a different soil type, silvopastures had a bulk density of $0.82 g/cm^3$ while open pastures had a bulk density of $1.01 g/cm^3$; forests fell in the middle at a bulk density of $0.86 g/cm^3$ (Staley et al., 2008).

Trends in soil organic matter content, measured by LOI and percent total carbon, suggest a divergence of pasture systems from the forest treatment group. Percent total carbon significantly increased in the forest group soils, and while not significant, this group also increased in percent organic matter measured by LOI. In both pasture treatment groups, percent total carbon remained statistically similar pre and post-treatment (Table 4). It is expected that soil organic matter increased across the site after the initial timber harvest due to inclusion of woody material through skidding trees. The heterogeneous nature of skidding locations in forests and silvopastures may have led to a higher variability in soil organic matter than that seen in open pastures where skidding location was not restricted by residual trees. Increases in soil carbon due to inclusion of woody material from timber harvesting have been documented in similar regional forest soils (Fahey et al., 2005). The significant increase in soil organic matter in the forest group soils is likely a result of slower decomposition rates in this system when compared to the other two groups. Past research had found that tree debris decomposed faster in silvopastures than in forests (Gonzalez et al., 2010). Pasture treatments may have experienced higher decomposition rates due to hoof pressure, raw manure and nitrogen additions from livestock altering soil ecology. For example, grazing by goats within a loblolly-pine silvopasture increased the soil nitrogen and phosphorus levels over a period of three years (Nyakatawa et al., 2012). Additionally, in an Appalachian study which compared open pastures, forest, and silvopastures, researchers concluded that nitrate leaching was reduced in silvopastures compared to other treatments (Boyer and Neel, 2010).

Over the course of this study percent total N, PMN, and P increased in silvopastures, open pastures, and woodlot treatment groups. The degree of increase was similar for both nitrogen measures between groups with two exceptions: the forest group caught up to the other two in percent total N post-treatment and the open pasture had significantly less PMN post-treatment than the other two treatment groups (all treatment groups had statistically similar PMN in 2012). Increases in soil N and P availability are expected post timber harvesting due to incorporation and decomposition of organic matter. Past research on the effects of whole-tree timber harvesting has shown an increase of N in waterways due to increases in soil decomposition rates leading to more available N in soils, especially during the first year after harvesting (Burns and Murdoch, 2005; Campbell et al., 2007; Hornbeck et al., 1990; Mann et al., 1988; Martin et al., 1985; Pardo et al., 1995). Lesser amounts of available N may be available in open pastures due to greater rates of N leaching during the first year after timber harvesting.

At the Hubbard Brook Research Forest in New Hampshire, rates of N leaching after whole tree timber harvesting were greater in clearcut watersheds when compared to a stripcut watershed where trees were maintained (Campbell et al., 2007). Research from northern Florida suggests a potential for silvopastures to have higher nitrogen retention than open pastures and forest plantations (Bambo et al., 2009). An important factor to note from that study is that the forest plantation treatment differed from the others in that it received two understory glyphosate treatments during the sampling period (Bambo et al., 2009), possibly causing more nitrogen leaching than would be found in a forest with a living understory plant community. It is probable that less PMN was found in the open pasture group here due to greater losses through increased leaching during the first year after timber harvesting. This could be due to a lack of living plant roots to capture available N prior to any understory revegetation post timber harvesting.

This research was not able to clearly address changes in base cations. Ca, K, and Mg were highly variable across the site. Base cation losses in soils are expected during the first few years after heavy timber harvesting due to a temporary disparity between decomposition and nutrient uptake rates. Regional research suggests that these losses are only temporary as pre-harvest levels will be realized after a few years (Likens et al., 1998; Mann et al., 1988). More time is needed to fully tease out discrepancies in base cation concentrations between treatment groups. While the open pasture and silvopasture groups seem to be following similar trends for Ca and Mg when compared to the forest group, the forest and silvopasture groups experienced more similarities than the open treatment group in terms of K. Overall, the relative changes of these base cation pools are low and with high variability; analysis of these nutrient dynamics would have benefited from a longer interval between sampling dates.

From a conservation perspective the retention of living trees plays a critical role in reducing the loss of nutrients from a site after heavy disturbance or conversion to agriculture. Lessons from past work suggest that revegetation of the understory of a forest stand post disturbance is of importance to reduction of nutrient leaching (Bambo et al., 2009; Campbell et al., 2007). In forest conversion to pasture systems, it is critical to establish forages as soon as possible so they're able to retain nutrients on the site. Research in silvopastures on sandy soils in Florida support the value of trees in nutrient retention. Researchers found that the capacity of silvopastures to hold phosphorus was higher than comparable treeless systems, suggesting the potential for silvopastures to retain nutrients (Nair et al., 2007a). Nutrient losses from livestock excretion have been considered significant losses to the system pools in open pastures (Sharpley and West, 2008). However, physical removal of nutrients though livestock may not pose a risk to nutrient loss in pasture systems. One study on silvopastures in Europe found the total output of nitrogen and phosphorus through livestock was equal to or less than contributions into the system from atmospheric deposition (Moreno and Pulido, 2009). This is logical because the net uptake of nutrients in livestock over a 1-2 day grazing period is much smaller than gross nutrient cycling through livestock. Rotational grazing is the suggested mitigation strategy to reduce losses of nutrients due to livestock in pasture systems (Sharpley and West, 2008).

CONCLUSIONS

The conservation benefits of forest conversions to silvopastures depend on what systems they are being compared to. When comparing forest conversions to silvopasture or open pastures, silvopastures are better buffered against soil compaction and nutrient losses due to the benefits of residual tree roots. However, silvopastures may experience greater amounts soil compaction, due to livestock, and reduced soil organic matter content, due to increases in nutrient cycling when compared to heavily thinned forests. Timber harvesting was a significant player in altering understory plant communities but these communities had yet to diverge between open pastures, silvopastures, and forest treatments. More time is needed to document divergence of understory plant communities and soil nutrient dynamics between forests, silvopastures, and open pastures.

This study was limited by a small sample size and the systems approach to its design. Future research should investigate the functional mechanisms behind ecosystem changes when converting forestland to pasture. Two interesting places to start would be the functional mechanisms behind the loss of lowbush blueberry in both pasture treatment groups and why orchardgrass treatments witnessed increases in pH. Will other native forest plants fade out in the long-term? What component of livestock inclusion might lead to these changes? Will orchardgrass treatments continue to see increases in pH over time?

Long-term effects of forest conversion to pasture are understudied and long-term experiments across differing forest types do not exist. Research building on the results of this study should incorporate larger sample sizes and multiple management options, such as alternate tree densities. For example, is there a tree density that encourages silvopastures to have ecological characteristic similar to forest while maintaining agricultural productivity? Or does forest conversion to pasture inherently lead to a degree of soil degradation and loss of native plants, regardless of alternative management systems like silvopasture?

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APPENDICES

APPENDIX A: INTERVIEW QUESTIONNAIRE USED FOR RESEARCH IN CHAPTER 1

- What is your main occupation?
- How long have you been the principal operator of a farm?
- How many years have you been on your current farm?
- What are your primary farm products?
- How many head of each type of livestock do you have?
- Why do you incorporate silvopasture systems into your farm management?
- How did you first learn about silvopasture?
- Prior to implementing silvopasture systems on your farm, what was your experience with silvopasture?
    - What was your knowledge of the practice prior to implementing it on your farm?
    - Had you actually practiced silvopasture prior to implementing it on your own farm?
- Do you utilize other agroforestry practices on your farm?
- Do you own a farm woodlot and if so do you manage it?
    - Have you ever worked with a forester to manage your farm woodlot?
    - What do you manage your farm woodlot for?
    - How many acres each of established silvopasture, woodlot planned to be converted to silvopasture, and woodlot indefinitely managed as woods do you have on your farm?
- How long have the silvopasture systems on you farm been in existence?
    - What prescription did you use to establish these silvopastures (e.g., tree planting spacing, residual basal area, etc.)?
        - How did you arrive at that prescription and did you conduct the work yourself?
        - If forest conversion, how did you utilize the wood volume removed?
        - Did you work with a forester and was the forester supportive of silvopasture?
- How do you incorporate silvopasture systems into your farm management?
- What do you consider a desirable pasture to be and why?
- How do you manage livestock within your silvopasture systems?
    - What type of livestock do you incorporate into your silvopasture systems?
    - Do you use rotational grazing techniques?
        - What rotation lengths (days) do you utilize?
        - How many rotations do you get out of your silvopastures each year?
        - How many animals per acre are on silvopastures in each rotation?
    - During what calendar periods are livestock incorporated into your silvopastures?
    - Are there times of the year when silvopastures are especially valuable or not valuable?
    - Do you have concerns regarding animal health in silvopastures?
- How do you manage the trees in your silvopasture systems?
    - What forest products are you managing for?
    - What species of trees do you prefer to manage for?
    - Have you converted fields to silvopastures or forests to silvopastures or both?
    - How do you approach regenerating trees in silvopastures?
    - Have you realized any direct economic benefit from the trees in your silvopastures?
    - Are you aware of potential tree health problems in your silvopastures, and what, if any steps, do you take to prevent or respond to those problems?
- How do you manage forages in your silvopasture systems?
    - What types of forages do you manage for?
    - Are there plants that interfere with forage production in your silvopastures (weeds)?
    - Do you perceive a difference in production between your open pastures and silvopastures?
    - Do you consider forage availability when rotating livestock into and out of silvopastures?
- Economics
    - How much money do you have invested in the silvopastures on your farm (establishment, management, indirect costs)?
    - How much revenue do you receive from the silvopastures on your farm (trees, livestock, indirect)?
- What are any major challenges you face in managing silvopastures?
- Is silvopasture something you are going to continue to practice on your farm?
- Do you have any advice for farmers who are considering the use of silvopasture?
- Would you identify areas of research in relation to silvopasture that would benefit you as a farmer?
- What educational resources would you like to have to help you better manage your silvopastures?

APPENDIX B: IMAGES OF SILVOPASTURES AND PASTURED WOODLANDS TAKEN ON FARMS IN NEW YORK AND NEW ENGLAND AS PART OF RESEARCH IN CHAPTER 1

Image 1: Batten strip used to secure high tensile electric fence to living tree. This photo was taken in a Northeast silvopasture during its first year of establishment. It is best not to use sawlog quality trees for living fence posts because of loss of quality and risk of injury to potential sawyers of the log.

Image 2: Compression springs incorporated into high tensile electric fencing around a new Northeast silvopasture. These springs allow the fence to flex and recover during damage from falling trees or limbs. Additionally, compression springs allow the fence to stretch as tree stems move during wind events.

Image 3: Pigs being pastured in woodlands on a Northeastern U.S. farm. The farmer identified this as a form of silvopasture but it was classified as pastured woodlands due to monthly/yearly livestock rotations and no management of trees.

Image 4: This image, from a Northeastern U.S. farm, depicts the differences between continuous pasturing of pigs (left) and rotational grazing of cattle. While neither system can be defined as a silvopasture due to lack of tree management, lessons regarding grazing management are evident.

Image 5: Individual tree fencing being used to protect a young fruit tree from sheep in a Northeast silvopasture. Note the mulch and downspout from a gutter system being re-purposed to protect from basal damage due to rodents.

Image 6: Non-electrified electric fencing being used to protect a young tree seedling from cattle in a Northeast silvopasture planting. Note the heavy grass competition due to decomposition of mulch around the base of the planted tree seedling.

Image 7: Black locust coppice system being utilized to regenerate Northeast silvopastures. Note the high stocking rate of stems which will encourage strait, clear wood but may require pre-commercial thinning.

Image 8: High density oak/hickory/maple silvopasture converted from a hardwood stand on a Northeast farm. Very little forage is available, likely due to high residual tree density.

Image 9: Low density, uniformly spaced oak and maple silvopasture after 20 years of establishment on a Northeast farm. Note the consistent forage layer and persistence of hay-scented fern in the foreground of this image.

Image 10: Patch silvopasture created from a forest comprised of oak and maple on a Northeast farm.


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Image 11: Variable density oak and maple silvopasture converted from a forest on a Northeast farm.

Image 12: Open pasture created from a forest with a few widely spaced residual trees on a Northeast farm. The low tree density classifies this as an open pasture and not a silvopasture.

Image 13: Crown dieback in a wolf tree found an in open pasture on a Northeast farm. Crown damage is possibly due to root compaction from livestock congregating in the shade of this stand-alone tree.

Image 14: Open field edge silvopasture converted from a forest with uniform spacing of eastern white pine on a Northeast farm.

Image 15: Open field edge silvopasture converted from a forest with a gradual increase in density of residual eastern white pine from open field to the fenceline in a closed canopy forest on a Northeast farm.

Image 16: Black walnut silvopasture with an understory of orchardgrass on a Northeast farm. Forage was productive despite the high relative density of trees, possible due to low foliage density of black walnut canopies.

Image 17: Black locust silvopasture with a small component of black walnut on a Northeast farm. This 20 year old plantation has been commercially thinned twice for black locust fence posts.

Image 18: Mixed conifer plantation used as an outdoor living barn during extreme winter weather events on a Northeast farm. Note the sparse forage layer, likely due to intentionally high tree density for shelter.

Image 19: Outdoor living barn of balsam fir bounded by eastern white pine being maintained for summer shelter from biting flies and heat in addition to timber production on a Northeast farm.

Image 20: Apple orchard silvopasture which is periodically grazed by sheep on a Northeast farm. Note the orchardgrass in the foreground of the image.

Image 21: Highbush blueberry patch which is periodically grazed with sheep on a Northeast farm. Although not silvopasture due to lack of trees, the management and structure of this system shares many similarities to silvopasture.

Image 22: Maple sugarbush which has been grazed by cattle during dry periods of the summer for over 25 years on a Northeast farm. The farmer intentionally set tubing high off the ground and only incorporates cattle for short periods. Note the sparse availability of desirable forage.

APPENDIX C: FARMER STATEMENT EXPRESSING THE IMPORTANCE OF WORKING WITH A FORESTER WHEN ESTABLISHING A SILVOPASTURE, FROM RESEARCH IN CHAPTER 1

I started the whole process down there and was not happy with the way it was going. They had a forester, the logging company had a forester.

And he was a really nice guy and . . . you know him but I'm not even going to mention his name.

But I was just not happy with what I thought was how they are handling it. And I was talking to [consulting forester, name removed] one day and he was like [landowner, name removed] I am your forester, that's my job is to do that. And I said oh really well haul yourself over here [because I contracted with a company and have a timber harvest going on].

And he did and it was very interesting because my agreement with them was they would not cut any of the oaks. And there were, one of the things that got me was my neighbor, whose a big logger guy he's looking at the log pile and says wow you've got some nice oaks in there.

And I'm going there's not supposed to be any oaks in there, what the heck do I know, I'm the landowner you know, and you know a landowner that does therapy for a living.

So [consulting forester, name removed] came, we all walked and the logger comes out of the big machine and we're like . . . god these guys are all six-foot-eight and 13 feet wide you know . . . and we're talking and I said you were supposed to leave all the oaks, and he says we're not taking any oaks and [consulting forester, name removed] says well there's a stump there and there's a stump there.

There were four stumps within 15 feet, oak stumps.

And the guy said we're only taking the bad, the bad oaks.

And at that point he and [consulting forester, name removed] went off about 30 feet and had a conversation.

And when they came back they [the logging contractors] didn't cut any more oaks.

And that's why foresters are really useful. I mean they know what they are doing. And I didn't know, I really didn't know that that was his job was to negotiate that and supervise it. Yeah.

I just had to have a forester to have a management plan. I thought that's what they did wrote a management plan then disappeared.

APPENDIX D: IMAGES OF RESEARCH IN CHAPTERS 2 AND 3: PRE-TREATMENT (2012), 1 YEAR POST TREATMENT (2013), AND 2 YEARS POST TREATMENT (2014)

Pre-treatment

Establishment Year, 3 Months Post-Harvest. Open pasture on left, silvopasture on right

Silvopasture One Year Post-Treatment (2013)

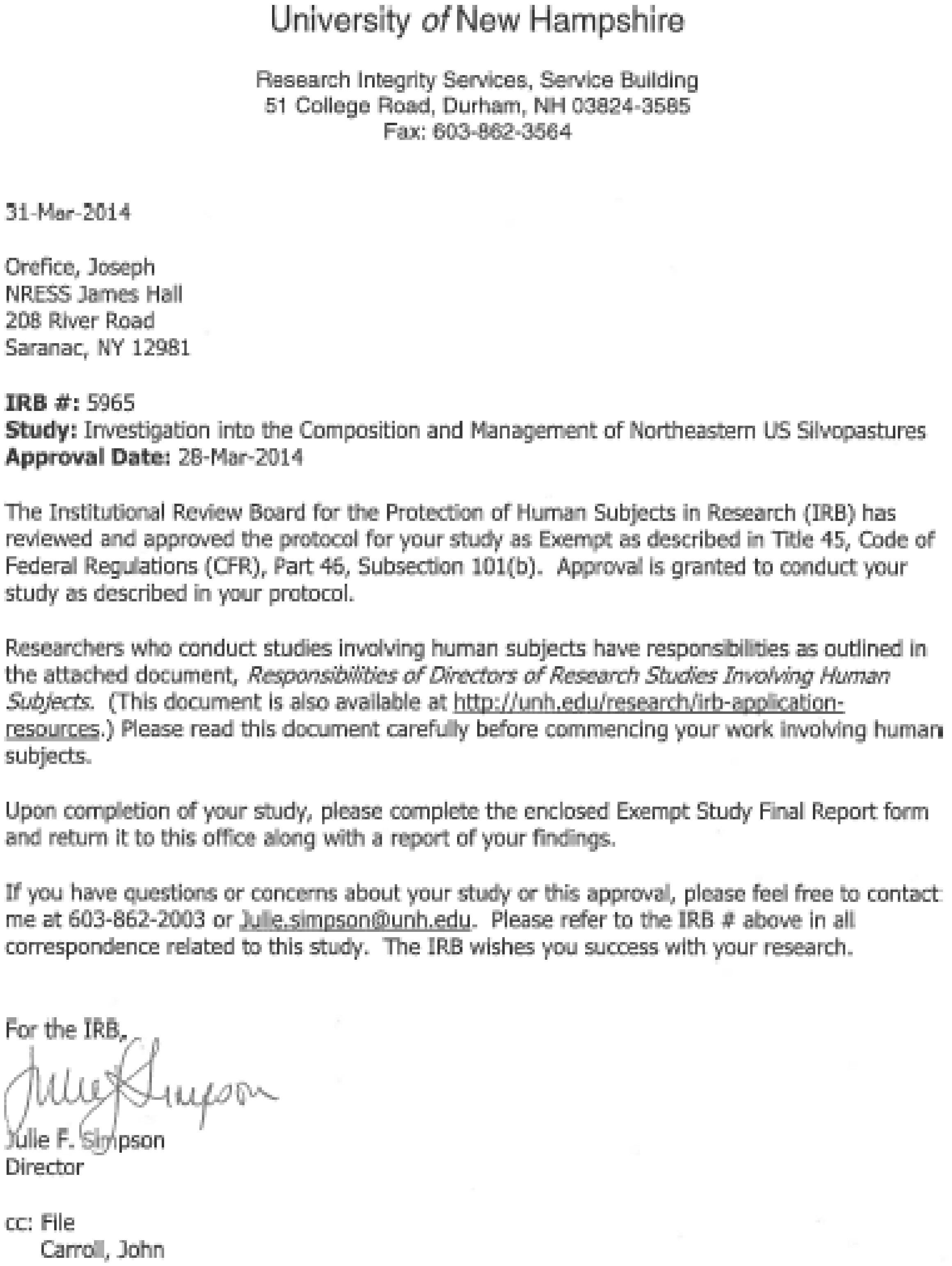
Silvopasture Two Years Post-Treatment (2014)

Orchardgrass in a Silvopasture Two Years Post Treatment, Smooth Bromegrass is the Treatment Group on the Right.

Open Pasture Two Years Post-Treatment (2014)

Woodlot Two Years Post-Thinning (2014)

APPENDIX E: UNH INSTITUTIONAL REVIEW BOARD (IRB) APPROVAL LETTER FOR USE OF HUMAN SUBJECTS IN RESEARCH



University *of* New Hampshire

Research Integrity Services, Service Building
51 College Road, Durham, NH 03824-3585
Fax: 603-862-3564

31-Mar-2014

Orefice, Joseph
NRESS James Hall
208 River Road
Saranac, NY 12981

IRB #: 5965
Study: Investigation into the Composition and Management of Northeastern US Silvopastures
Approval Date: 28-Mar-2014

The Institutional Review Board for the Protection of Human Subjects in Research (IRB) has reviewed and approved the protocol for your study as Exempt as described in Title 45, Code of Federal Regulations (CFR), Part 46, Subsection 101(b). Approval is granted to conduct your study as described in your protocol.

Researchers who conduct studies involving human subjects have responsibilities as outlined in the attached document, *Responsibilities of Directors of Research Studies Involving Human Subjects*. (This document is also available at http://unh.edu/research/irb-application-resources.) Please read this document carefully before commencing your work involving human subjects.

Upon completion of your study, please complete the enclosed Exempt Study Final Report form and return it to this office along with a report of your findings.

If you have questions or concerns about your study or this approval, please feel free to contact me at 603-862-2003 or Julie.simpson@unh.edu. Please refer to the IRB # above in all correspondence related to this study. The IRB wishes you success with your research.

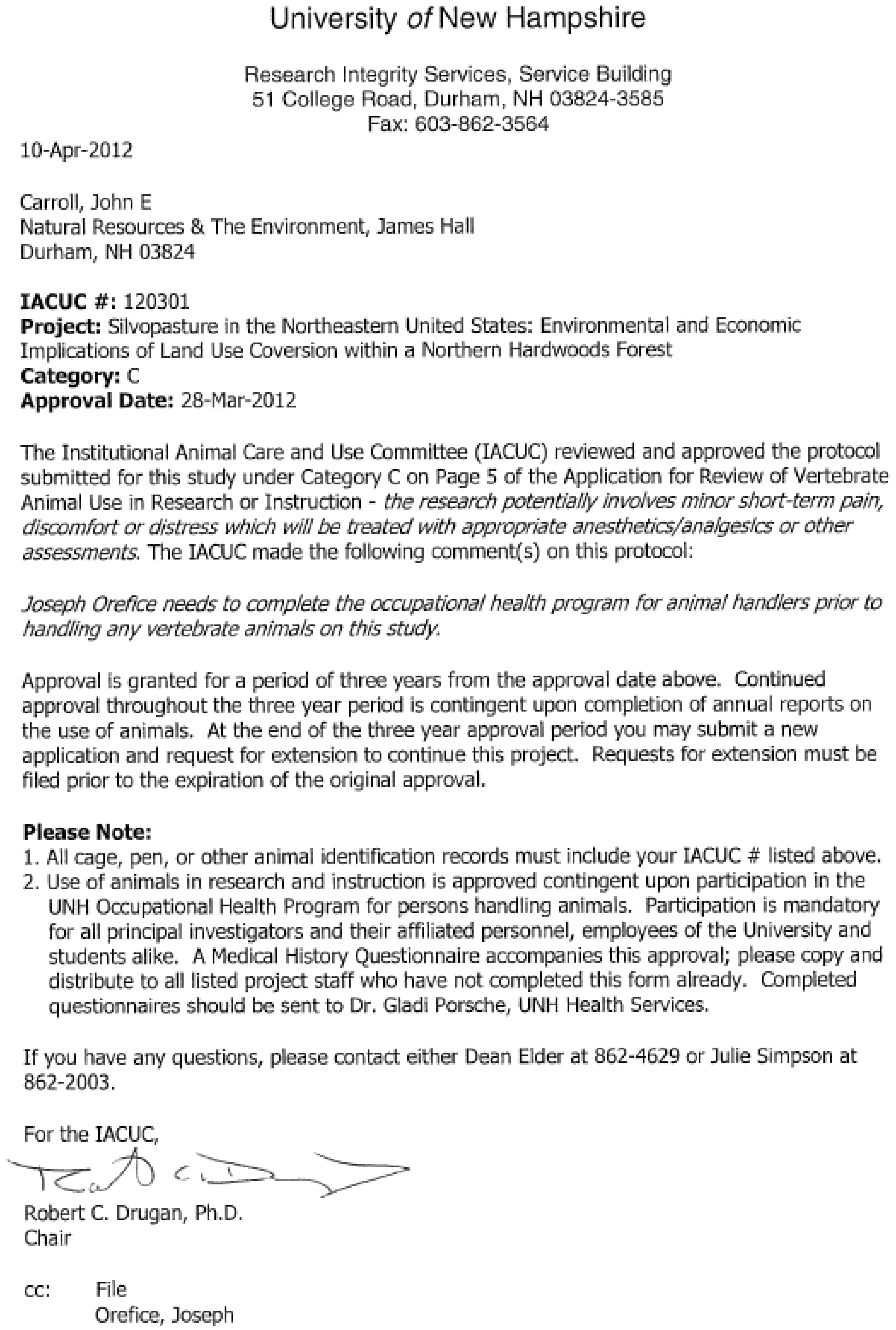
For the IRB,

Julie Simpson

Julie F. Simpson
Director

cc: File
Carroll, John

APPENDIX F: UNH INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE (IACUC) APPROVAL LETTER FOR THE USE OF VERTEBRATE ANIMAL IN RESEARCH



University *of* New Hampshire

Research Integrity Services, Service Building
51 College Road, Durham, NH 03824-3585
Fax: 603-862-3564

10-Apr-2012

Carroll, John E
Natural Resources & The Environment, James Hall
Durham, NH 03824

IACUC #: 120301
Project: Silvopasture in the Northeastern United States: Environmental and Economic Implications of Land Use Coversion within a Northern Hardwoods Forest
Category: C
Approval Date: 28-Mar-2012

The Institutional Animal Care and Use Committee (IACUC) reviewed and approved the protocol submitted for this study under Category C on Page 5 of the Application for Review of Vertebrate Animal Use in Research or Instruction - *the research potentially involves minor short-term pain, discomfort or distress which will be treated with appropriate anesthetics/analgesics or other assessments*. The IACUC made the following comment(s) on this protocol:

Joseph Orefice needs to complete the occupational health program for animal handlers prior to handling any vertebrate animals on this study.

Approval is granted for a period of three years from the approval date above. Continued approval throughout the three year period is contingent upon completion of annual reports on the use of animals. At the end of the three year approval period you may submit a new application and request for extension to continue this project. Requests for extension must be filed prior to the expiration of the original approval.

Please Note:

1. All cage, pen, or other animal identification records must include your IACUC # listed above.
2. Use of animals in research and instruction is approved contingent upon participation in the UNH Occupational Health Program for persons handling animals. Participation is mandatory for all principal investigators and their affiliated personnel, employees of the University and students alike. A Medical History Questionnaire accompanies this approval; please copy and distribute to all listed project staff who have not completed this form already. Completed questionnaires should be sent to Dr. Gladi Porsche, UNH Health Services.

If you have any questions, please contact either Dean Elder at 862-4629 or Julie Simpson at 862-2003.

For the IACUC,

Robert C. Drugan, Ph.D.
Chair

cc: File
Orefice, Joseph