INTERDISCIPLINARY INTEGRATION OF SILVOPASTURE AMONG LIVESTOCK GRAZING SYSTEMS AS A STRATEGY FOR NATURAL RESOURCE MANAGEMENT

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By

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The undersigned, appointed by the dean of the Graduate School, have examined the dissertation entitled

INTERDISCIPLINARY INTEGRATION OF
SILVOPASTURE AMONG LIVESTOCK GRAZING SYSTEMS AS A STRATEGY FOR NATURAL RESOURCE MANAGEMENT

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a candidate for the degree of doctor of Natural Resources,

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DEDICATION

To Mechelle Esparza-Harris, my mama, whose endless love and support I cherish and wish everyone could experience. This work is dedicated to you. Thank you for your unwavering sacrifice, continuous guidance, endless support, and undying love during this process.

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ABSTRACT

For centuries, animal and natural resource management have maintained a balance of ecological sustainability and provisioning basic needs for human survival. Over time, civilizations evolved through the rise of agriculture, migration and trade, and technological advancements influencing land use change and natural resource management. However, land use decisions to meet the growing demands of society have contributed to modern issues, including climate change, natural resource depletion, landscape homogenization, fragmentation, and environmental degradation. To date, these issues are hindering agricultural communities' capacity in adapting to threats and maintaining a balance between ecological sustainability and productivity. This research incorporated qualitative and quantitative research methods aimed at assessing current livestock and resource management practices vulnerable to stressors, threatening sustainability of livestock systems and natural resources. Furthermore, this research focuses on evaluating avenues towards the integration of silvopasture within livestock systems to build adaptation and resilience within livestock production and natural resource management.

A qualitative case study was conducted internationally to understand the stressors impacting pastoral and agricultural communities, and the potential for silvopasture components to aid in adaptation and resilience among commons resource management (Chapter 2). This study showed majority of communities were engaged in herding and farming activities, which were impacted by stressors causing constraints on commons resources and ensuing conflict between herders and farmers. Chapter 3 explored current livestock and forest management practices among Missouri livestock producers, assessing producers' perceptions and interests in the practice of silvopasture within livestock operations. Missouri livestock producers reported engaging in some level of livestock grazing and forest management practices, though gaps in understanding of practice and barriers hindered implementation of silvopasture. Chapter 4

examined using livestock for native landscape restoration by managing the invasive species *Sericea* lespedeza. This study showed that goats grazing has the capacity to impact the relative abundance of some vegetation classes following an initial grazing season. Grazing sericea lespedeza also showed benefits of parasitic control. These studies indicated interest in and applicability of silvopasture, demonstrating the opportunity to integrate the practice within livestock systems to enhance capacity for adapting to threats, conserving, and managing natural resources, restoring landscapes and gaining resilience.

Chapter 1: Introduction - Literature Review

Background, Problem Statement, and Research Objectives

Native and naturalized animals have maintained an important role in the environment and society by contributing to ecological balance, landscape management, and economic and human development (Herrero et al., 2009; Herrero et al., 2013). This includes the cycling of nutrients, influencing ecosystem interactions, and utilizing and converting plant materials for production, human consumption, and growth (Mitchell & Kirby, 1990; Janzen, 2011; Kremen & Merenlender, 2018). During earlier periods of human development, humans functioned in balance with natural resource management and animal husbandry. This balance was maintained because of an abundance of natural resources accessible to novice civilizations, thus having a minimal impact on the landscape.

Over time, the evolution of these civilizations increased pressure on natural resource usage with subsequent development and technological advancements to meet demand for growth. This resulted in increased human-induced agricultural and natural resource management activities, which began to change the landscape (Herrero et al., 2015). Such activities included extreme landscape manipulation, over-harvesting resources, and intensification of livestock production practices, causing changes in ecosystem composition and landscape dynamics (Janzen, 2011; Opio, 2011)**.** These activities have led to reduced resource availability, biodiversity loss, greenhouse gas emissions, and climate change, which is threatening present-day ecological sustainability and agricultural productivity (FAO, 2006; Steinfeld et al., 2006; Gill et al., 2010; Opio, 2011).

Agriculture and livestock production are dependent on land and natural resources, thus sensitive to climatic impacts such as temperature and precipitation changes, extreme weather events, and ecosystem disruption. Ongoing actions in land use, development, natural resource management and intensified agriculture have exacerbated such impacts, adversely affecting agricultural actors' capacity for adaptation (Janzen, 2011; Grossi et al., 2019). Moreover, unsustainable human-induced activities are reducing resilience amongst agricultural communities, intensifying pressures on natural resources, amplifying climate change, and threatening food security. This warrants the exploration of strategies for integrating livestock within sustainable land use and natural resource management, as well as climate adaptation and mitigation practices to build resilience towards ecological sustainability and agricultural productivity.

This review serves to outline the distinct change in human resource management and activities, from historical integration of livestock to present-day intensified livestock production. By reviewing past practices and systems and examining the changes in human land use and management, this review aims to justify the case for the reintegration of livestock within current natural resource management practices. To date, approaches have been assessed and researched for integrating livestock in restoring ecosystems, conserving natural resources, and mitigating climate change impacts (Kremen, 2020). Continued investigation is necessary for ensuring resource management and agricultural productivity.

These efforts have enhanced Indigenous and traditional management practices such as integrative livestock management systems and agroforestry to meet current societies demand (Herrero et al., 2009; Kremen & Merenlender, 2018; Kremen, 2020; Kletty, 2023). Silvopasture, the agroforestry practice involving the integrated management of woody perennials (trees or shrubs), forage or crops, and livestock, presents the opportunity to address productivity objectives (Clason & Sharrow, 2000). By exploring silvopasture this review seeks to show the systems' capacity for facilitating climate change adaptation and mitigation, sustainable resource management, landscape diversification, and ecosystem restoration (Kendall et al., 2006; Rigueiro-Rodríguez et al., 2011; Udawatta et al., 2022; Kletty, 2023). This review also aims to examine the documented challenges to integrating livestock within natural resource management such as silvopasture systems, thus warranting further exploration into addressing research gaps surrounding silvopasture and integrated livestock systems.

Traditional Integrated Livestock Management Systems and Evolution of Livestock Farming

Land use and natural resource management by humans have evolved through time to meet the societal demand of the respective era. Within the Paleolithic and Mesolithic periods (2.5 million years ago), hunter-gatherer culture consisted of societies characterized by egalitarianism, communal, nomadic, and subsistence lifestyles. These hunter-gatherer societies continuously migrated among vast areas of land for gathering, hunting, fishing, trapping, and foraging of food and raw materials, utilizing fire to aid in management and provisioning of resources (Winterhalder, 2001; Bowman et al., 2011; Barnard, 2020). The use of anthropogenic fire to modify the landscape improved the predictability, efficiency, and availability of resources for survival and to support a mutual exchange economic system (Scherjon et al., 2015).

During the Neolithic – Agricultural Revolution 12,000 years ago, hunter-gatherer cultures began to shift towards agrarian societies driven by farming and livestock production to support the population's growing economy (Winterhalder & Kennett, 2006). In contrast to hunter-gatherer cultures, agrarian societies created socioeconomic relationships dependent on hierarchy, developed permanent settlements to support denser populations, and relied on extensive human and animal labor. Whitehouse and Kirleis (2014) describe this transition, documenting the change in the interaction between humans and the environment with respect to access to food. This earlier development involved abandoning hunting and foraging activities for agrarian practices including farming for root crops, cultivation of herbs and plants for medicinal purposes, management of shrubs and trees for food products (i.e., fruits and nuts) and materials, and the domestication of animals (Miller & Nair, 2006; Winterhalder & Kennett, 2006; Whitehouse & Kirleis, 2014; Scanes, 2018).

An early agrarian practice commonly used within tropical ecosystems was swidden agriculture, also known as shifting cultivation (Deneven et al., 1984; Raintree & Warner, 1985; Eden & Andrade, 1987; Dufour, 1990). This practice involved the clearing of forested areas by felling trees and burning stumps to produce agricultural crops for a short period of time. Following cultivation for a few years, the land would be rested and allowed to fallow, leading to natural regeneration of forest (Deneven et al., 1984). Such practice was prevalent among Amazonia, Boreno, and Central African civilizations to increase the capacity for various food products, and towards enhancing forest tree species selection to produce tree-crops and fruit (Harris, 1971; Dove, 1983; Deneven et al., 1984; Balée & Gély, 1989). Previous research demonstrates that swidden agriculture provides beneficial conditions for agriculture with minimal ecological disturbance (Herrera et al., 1981; Ewel, 1986; Eden & Andrade, 1987). This practice maintained the balance of environmental impacts and agricultural production to support low-density populations. Deneven (et al. 1984) compared the similarities of swidden to agroforestry systems as complex sustainable management systems, particularly during early stages of forest fallow, which provided ecological and production benefits. These included diversification of the forested area and growing plant species, while providing habitat, opportunities for hunting and forest products for medicine, fiber, and fuel (Raintree & Warner, 1985; Dufour, 1990).

Another example of an early agrarian practice among populations within the highlands of Southern China is *taungya*, a cultivation strategy used in combination with forest management within mountainous areas with limited potential for agriculture (Raintree & Warner, 1985; Menzies, 1988). The practice of taungya, presently known as the forest village system, involved the clearing of a forest stand to temporarily produce agricultural (food) crops. This was followed by the interplanting of selected timber species (e.g., *cunninghamia*) to establish tree plantations, cultivate, and produce forest products, altering the natural composition within mountainous terrains, characterized as traditional intercropping systems (Menzies, 1988). Eventually, the canopy closes preventing any further agricultural use, and the land is used solely for the timber crop until the cycle is repeated following harvest of the timber rotational systems.

During the transition period between hunter-gatherers and agrarian societies, livestock farming, the practice of raising animals for products, became intertwined with management of the natural landscape. As civilizations developed, animals became domesticated, starting with sheep and followed by goats, to produce meat, milk, and fiber (Scanes, 2018; Arbuckle & Hammer, 2019). Over time, the domestication of these species became integral to hunter-gatherer and agrarian societies, originating in Western Asia, which transitioned to nomadic herding to supplement the availability of animal resources, known as pastoralism (Arbuckle, 2014; Arbuckle & Hammer, 2019). Subsequent domestication of horses, cows, and pigs would occur as agrarian civilizations expanded (Arbuckle, 2014; Scanes, 2018).

Pastoralism: Nomadic and Semi-nomadic Transhumance Livestock Movement

Pastoralism originated within Southwest Asia, known commonly as the Fertile Crescent with the initial domestication of livestock (Peters et al., 2017; Arbuckle & Hammer, 2019). This traditional practice is widely characterized by the movement of domesticated animals seasonally to ensure access to resources supporting subsistence lifestyles, and animal husbandry as a primary economic activity. Arbuckle and Hammer (2019) dismantle this general ethnohistoric characterization of pastoralism during the Neolithic era because it infers that communities relied on pastoral herding for majority of subsistence and ceased agricultural practices. Furthermore, these theories support the separation of nomadic pastoral populations and settled farming civilizations. Rather, Arbuckle and Hammer (2019) characterize the practice of pastoralism as being diverse, flexible, and adaptive throughout different time periods and regions (Honeychurch & Makarewicz, 2016; Wezel et al., 2020).

Evidence shows during the Neolithic era pastoralism involved a range of animal husbandry practices interconnected within sedentary communities practicing cultivation and local livestock farming (Arbuckle & Hammer, 2019). This has been referred to as *agropastoralism*, a form of pastoralism that integrates livestock into the cultivation system by herding and cropping. These agropastoral communities tended to manage smaller herds and utilize locally harvested fields and agricultural products for feed. Reports show these communities began using husbandry strategies (e.g., penning, foddering, pasturing, and animal culling) that enhanced herd composition, permitted more targeted products, and enabled productive breeding of animals for food, materials, and labor. To support the growth in livestock activities, the mobility of animals became essential providing temporal and spatial diversification in resource management (Koocheki & Gliessman, 2005). Herders began traveling short distances locally to areas within or surrounding farming activities for supplemental feed resources (Dyson-Hudson & Dyson-Hudson, 1980; Koocheki & Gliessman, 2005; Arbuckle & Hammer, 2019).

With the progression of pastoral activities and increase in animal populations, variations of pastoralism developed within and beyond the Fertile Crescent region, based on the distance of travel required to access forage and water resources (Honeychurch & Makarewicz, 2016; Arbuckle & Hammer, 2019). Transhumance, a common form of pastoralism, with the action, or practice of moving livestock from one grazing area to another in a seasonal cycle has been shown to be prevalent among herders, specifically, within semiarid regions (Koocheki & Gliessman, 2005; Arbuckle & Hammer, 2019). Typically, this includes *vertical* mobility, moving animals in a seasonal pattern from mountain ranges to plains or between pastures of different altitudes. For example, grazing animals traveled within the cooler climate of the mountain highlands throughout the summer and then herded to the warmer lowlands' climate grasslands in the winter (Dyson-Hudson & Dyson-Hudson, 1980).

Eventually, pastoralism became prominent within the present-day Middle East region, due to the abundance of non-arable land (Dyson-Hudson & Dyson-Hudson, 1980). The dry climate and deficient soil, which lacked the fertility required for growing crops, limited farming for economic growth. Thus, nomadic societies began herding animals as a transient form of animal husbandry (Dyson-Hudson & Dyson-Hudson, 1980; Koocheki & Gliessman, 2005; Arbuckle & Hammer, 2019). This form of pastoralism is known as nomadic pastoralism, being irregular, opportunistic with *horizontal* mobility between similar altitudes to follow grazing resources. Nomadic herders (or pastoralists) would herd domesticated animals (sheep, goats, cattle, yak, llamas, camels) over long distances and across vast spans of vegetated lands to access forage and water, vital for survival and production of the animals (Honeychurch & Makarewicz, 2016). Other reasons for mobility included avoiding hazards in the physical and social environment such as pests and disease, reducing competition with other herders, avoiding authorities, and other social or political factors (Dyson-Hudson & Dyson-Hudson, 1980).

Abundant natural resources within a sparsely populated landscape were accessible to pastoralists, though this traditional livestock practice showed minimal impact on natural resources. Due to transient movement patterns and integrative strategies, with limited utilization of resources to support extensive or small subsistence-based communal activities and communities. Koocheki and Gliessman (2005) attribute the beneficial ecological impact of the pastoral system to traditional knowledge within agropastoral and nomadic societies into of forage and animal management (Wezel et al., 2020). Furthermore, pastoralists' knowledge and techniques have shown to directly and indirectly impact land use and natural resource management, such as increasing the biodiversity of vegetation and animal communities, and influencing landscapes through grazing behavior (Seid et al., 2016).

Pastoralists also used fire to manipulate the forest landscape to facilitate grazing and rejuvenate open grasslands, signifying an initial expansive integration of livestock and natural resource management (Seid et al., 2016). However, as pastoral communities tended to live on the margins of farming areas, incidences of encroachment occurred on frontier zones (e.g., bordering the desert) in which animal grazing minimally influenced soil and natural plant cover. This is due to the mobility of the practice that inherently prohibits overgrazing of vegetation sources. Moreover, pastoralism would significantly influence the socioeconomic aspect of civilization and land use management by facilitating expansion and interaction with other herding and farming communities, trading live animals' resources (e.g., meat, milk, fiber), and by-products (i.e., hide, horn, bore) for crops and other goods (Honeychurch & Makarewicz, 2016). The impact of pastoralism would amplify as the system began expanding further into additional areas of the Middle East, Asia, India, and Africa, with the practice adapting among the various regions and cultures (Dyson-Hudson & Dyson-Hudson, 1980; Rosen & Saidel, 2010; Honeychurch & Makarewicz, 2016; Arbuckle & Hammer, 2019; Kreutzmann, 2019; Smith, 2021).

Integrated Livestock Systems and Traditional Silvopasture

Global migration and settlement of humans between the Neolithic period and Middle Age (around 1,000 years ago) enhanced agriculture production to supply food crops and animal products to support the growth in civilization (Hartung, 2013). This growth has shown to influence the development of traditional and extensive livestock systems to produce livestock among various regions and natural landscapes. For example, in the mountainous terrain of Kyushu province, Japan, controlled burning practices were used to facilitate the preservation of pastures for cattle grazing (Kyushu Tourism Organization, n.d.). Pastures were burned in the early spring to ignite new grass growth, followed by the grazing of fields until early winter. To facilitate cattle production within Japan's forested areas, historical reviews also documented forest grazing as a traditional agropastoral customs practice contributing to the Japanese agricultural economy (Berque, 1979).

Across Europe, extensive livestock grazing systems were prominent, such as in the Scottish Highlands. These agricultural communities adhered to commons grazing pasture organizations that sustained shieling activities, temporary shelters that supported trasterminance movement between township farms and hill pastures (Bill, 1990; Coull, 1968; Pastos, 2009). Like transhumance movements, trasterminance characterizes the frequent vertical mobility of livestock within local areas. Bil (1990) noted the importance of the shieling activities in contributing to local agricultural systems and maintaining resource management. These activities ensured the herding system involved a combination of underutilized or sparsely populated land types (Bil, 1990). Periodically, these grazing areas included forested edges managed by deer hunting and marginalized areas unsuitable for farming. Around southern Spain shepherds used trasterminance movement and communal grazing as well for herds (e.g., Andalucia cattle) that grazed freely, unenclosed across extensive areas (Jordan, 1993; Caballero et al., 2009; Velamazán et al., 2024). Other parts of Europe have shown to incorporate livestock within mixed agricultural production systems, such as grazing sheep within groves, vineyards, and orchards for forage management towards the end of the harvest season (Papanastasis et al., 2009).

Within the European-Mediterranean region traditional silvopasture systems became customary practices for low-input, diverse agricultural systems that contributed to biodiversity and resource management (Plieninger and Wilbrand, 2001; Caballero et al., 2009; Papanastasis et al., 2009; Carreira et al., 2023). Originally, this included the integration of livestock within olive tree orchards with or without the inclusion of cereal crops in Greece (Papanastasis et al., 2009). These traditional silvopasture systems involved the mechanical removal of vegetation and fire to open the landscape for grazing. Other forms included the pasturing of pigs in woodlands to promote the foraging of fruits and/or nuts (i.e., acorns) (Jørgensen, 2013). Such extensive livestock systems aided the development of integrated agricultural and natural resource management practices.

Thus, livestock farming would become integrated with management of agriculture, forest, and livestock husbandry, known as traditional agro-silvopastoral systems (Carreira et al., 2023). Upon the demand to expand agricultural production and pastoral activities, the forested landscape within the Mediterranean region was partially cleared through tree clearing and/or burning to form a mosaic landscape, prominent within the *dehesas* and *montados* ecosystems in Spain and Portugal, respectively (Plieninger & Wilbrand, 2001; Cabarello et al., 2009; Moreno & Pulido, 2009). Carreira et al. (2023) explores the establishment of these systems by discussing human interactions with the Mediterranean forested ecosystem, mainly highlighting the role humans had in shaping and managing the ecosystem to meet the agricultural needs in the region. Though humans managed these ecosystems to preserve the dehesas and montado characteristics, reviews have characterized these systems as being widely recognized for providing rich biodiversity and multiple ecosystem services, through management (Plieninger and Wilbrand, 2001; Moreno and Pulido, 2009). These systems consisted primarily of cork oak (*Quercus suber*) and holm oak (*Quercus rotundifolia*) at low density with an open herbaceous understory to support agricultural, forestry, and extensive grazing by domesticated livestock (Carreira et al., 2023). The dehesas would involve the management of oaks to produce acorns during the *Montanera*, acorn season. During this season Ibérico (Ibérian) pigs were allowed to forage mast (i.e., acorns) for fattening. A similar landscape in Portugal, the montados, would also support the combined practices of oak tree nut production, management of forage, and livestock foraging and grazing (Carreira et al., 2023).

Introduction of Livestock Farming on North American Natural Landscapes and Indigenous Natural Resource Management

Historically, the landscape of North America was characterized by extensive grassland, prairie, savanna, and woodland ecosystems. This consisted of dominant oak savannas and woodlands known as disturbance-adapted ecosystems, dependent on naturally occurring and anthropogenic fire management to maintain an open understory and inhibit the encroachment of trees and other woody plants (McPherson, 1997; Nelson, 2004; Hosten et al., 2006; Hanberry et al., 2017; Fowler & Beckage, 2019; San Francisco Estuary, n.d.). Savannas are distinguished as a transition ecotype between prairies and woodlands containing two main vegetation layers. This ecotype consists of widely spaced mature scattered trees with open crowns and a dense, multi-species native herbaceous groundcover (Nelson, 2004). Woodland ecosystems are known to have open canopies with a sparse mid-story and understory vegetation systems.

Research demonstrates that such ecosystems have been extensively managed by Native American populations that used traditional practices to modify the environmental conditions of these landscapes (Andersson & Moratto, 1996; Fowler & Konopik, 2007; Long et al., 2021). This management involved Native Americans utilizing diverse traditional practices to support hunting, gathering, and fishing activities for survival (Anderson & Moratto, 1996; Hosten, 2006; Fowler & Konopik, 2007; Long et al., 2021). Fire was the primary management tool in traditional agricultural practices and cultural customs (Fowler & Konopik, 2007; Long et al., 2021). Hosten (2006) described the use of fire to maintain the ideal conditions for optimal acorn productivity in oak ecosystems by controlling vegetation competition, managing stand health, and improving conditions for acorn collection and decomposition (Cole, 1977; Hosten, 2006). Fire was also utilized to promote stimulation and harvesting of berries and nuts, grasses and forbs, bulbs and roots, and medicinal plants (Long et al., 2021). Anderson and Moratto (1996) explains this use of fire along with other practices such as irrigating, pruning, sowing, selective harvesting, tiling, transplanting, and weeding, which optimized management of these habitats to provision plant and animal resources and materials.

Indigenous burning practices were also utilized to facilitate harvesting of wildlife (Fowler & Konopik, 2007). The use of burning to open and preserve the understory allowed for direct sunlight to support the year-round growth of native wildflowers, grasses, sedges, and forbs. This provided forage for an expansive number of common grazing species such as American bison (*Bos bison bison*), American elk (*Cervus canadesis*), and white-tailed deer. (*Odocoileus virginianus*). Also, burning practices enhanced habitation for other mammals, birds, reptiles, amphibians, and various invertebrates incorporated into Native American lifestyles (Nelson, 2004; Central Hardwoods Joint Venture, 2015; Missouri Department of Conservation, 2024a).

Such land stewardship was specifically documented among the Taino (Arawak) people. This Indigenous society is characterized as being the principal inhabitants of the West Indies, known as the Caribbean (i.e., Cuba, Jamaica, Hispaniola [the Dominican Republic] and Haiti, Puerto Rico), Greater Antilles Islands, and Florida (Stoneking, 2009; Picking and Vandebroek, 2019). During the late 15^{th} century, the Taino people managed the savanna grasslands through activities such as cultivation, and management of forest in valleys with fire. Hopper (2008) describes the dominant Taino livelihood consisting of farming practices, with supplemental practices of gathering, hunting, and fishing. Picking and Vandebroek (2019) describe farming techniques including the production of selective food crops consisting of – yucca, cassava, sweet potatoes, maize, beans, squash, arrowroot and cash crops – cotton, calabash, tobacco. These products were farmed and cultivated within growing fields which contained sustainable techniques such as mounds (*conucos*), terraces, or open fields. Mounds were arranged to impede erosion, improve drainage, facilitate weeding and harvesting, and maintain humidity. Trees were also managed and cultivated to produce non-timber forest products to include pine-apple, palm nuts, guava berries, and guayiga roots (Hopper, 2008; Picking and Vandebroek, 2019). Such agricultural practices were continuously utilized within landscapes managed with the use of fire, which would change dramatically with the introduction of livestock farming.

Historical reports indicate Spaniards began to settle amid the 1490s in Santo Domingo, the capital of the present-day Dominican Republic. To expand access to resources to stimulate the

Spanish economy by trade, ultimately initiating the transition of the landscape within the Americas (Picking and Vandebroek, 2019). With the purpose of colonizing the New World, agricultural products and domesticated animals (i.e., cattle, sheep, goats, pigs, chickens, mares) were transported to the West Indies (Bowling, 1942). Cattle, mainly the Andalucia breed, were introduced to the New World and flourished as the population grew in numbers and weight (Ficek, 2019). This breed could occupy native spaces, converting inhabitable areas into livable and exploitable landscapes. Also, with unmanaged grazing, these cattle prohibited forest growth by consuming young trees and vegetation in abandoned fields and savannas, converting agricultural fields into pasture. This created initial favorable conditions for European grasses and plants to replace native species.

Cattle further modified the landscape in ways that inadvertently benefited expansion of the Spanish colonization through slavery, trade, and colonial expeditions (Ficek, 2019; Picking and Vandebroek, 2019). Cattle were used as a source of food and labor, including transporting sugar cane and operating sugar mills (Ficek, 2019). Eventually, livestock farming expanded with productive breeding and raising cattle, becoming a fixed industry in the West Indies. This led to the exponential growth and subsequent selling of cattle to finance expeditions and engage in further colonization of North America (Bowling, 1942; Otto, 1986; Hart, 2016). Growth of the human and cattle population led to further incentivizing land use primarily for agricultural and livestock activities and development (Hart, 2016). Cattle provided economic opportunities by provisioning meat, fat, and hide, to finance plantations, land holdings, mining, and military posts (Otto, 1986; Hart, 2016; Ficek, 2019). This economic growth from cattle was reported by Otto (1986), in which South Carolina's cattle industry routinely shipped salt beef to the West Indies for goods and slaves, and to finance the growing rice industry (Hart, 2016).

Over time, the colonial nation's hunger for land and opportunities caused significant stress on the relations between Native Americans and colonists (Otto, 1986). During the 19th

century, various initiatives through campaigns, treaties, and laws were employed by the United States (U.S.) government to remove Native Americans from tribal lands (Akers, 1999; Bowes, 2014; Haake, 2017). This included the Indian Removal campaign, the Indian Treaties and Removal Act of 1830, and the Indian Appropriations Act of 1851. These governmental actions resulted in the systematic ethnic cleansing, forced displacement, and relocation of Native Americans, releasing millions of fertile acres and resources for settlers (Treuer, 2020). Furthermore, these methodical acts served as a pathway towards agricultural capitalism, imposing principles of foreign ownership on Indigenous inhabitants for control of resources (Bowes, 2014; Ficek, 2019) Also, this contributed to dismantling the traditional knowledge and belief on communal land connection, resource management, and land use (Lewis, 1995).

These events had an immense impact on the natural resources that Native Americans had stewarded through agrarian and forestry practices (Lewis, 1995). Native Americans' livelihood became further disrupted by the escalation in settlements and associated land use and free-range grazing practices (Coughenour, 1991). Historical texts further discuss the consequences of these events that resulted in the decline of buffalo populations, loss of native plant diversity, and reduction of natural resources (Lewis. 1995). Furthermore, Native Americans were restricted in their ability to hunt, fish, and gather traditional foods, as well as access natural resources impacted by farming, livestock grazing, fur trapping, mining, and logging industries (Sheridan, 1981; Lewis, 1995). Moreover, a substantial change in management of the landscape involved the suppression of fire, which had been traditionally used to maintain various ecosystems (i.e., savannas, prairies) (Benac & Flader, 2004; Fowler & Konopik, 2007; Hanberry et al., 2017). This caused a more significant change in the landscape, along with grazing practices and natural resource management policies that would be in contention because of ongoing land use priorities and consequences (Lewis, 1995). This is particularly seen in the management of land that involved livestock grazing in conjunction with wooded lots and low intensity forestry non-arable lands throughout North America.

Transition of Grazing Management Practices and Livestock Production within Temperature Agricultural Systems

Woodland and Forested Grazing

Unmanaged grazing behaviors of livestock, mainly cattle, fostered the incidence of prolonged forest grazing. Colonial livestock farmers considered forests an inexhaustible resource, which served as the principal source of extensive land for grazing, becoming a common form of grazing in North America. With the establishment of natural resource management agencies such as the U.S. Forest Service in 1905, management of these landscapes became of concern to conserve forests for continued use. Foresters and ecologists began to recognize the undesirable ecological changes the lack of grazing management caused on the natural cycles (i.e., water, carbon and nitrogen, plant, wildlife) of the forested ecosystem (Diller, 1935; Williams, 1951; Linnartz et al., 1966). Between the late 1920s – early 1930s, research began to uncover soil erosion and compaction, decline in forest competition and productivity, and destruction of wildlife habitats resulting from these changes (Chandler, 1939; Stoeckeler, 1959; Linnartz et al., 1966; Patric & Helvey, 1986; DeWitt, 1989; Newman et al., 1999).

Earlier studies have reported the constant movement of livestock throughout forested areas caused increased soil density in the forest understory (Chandler, 1940; Stoeckeler, 1959; Linnartz et al., 1966). Over time, the compaction of soil results in fewer and smaller pores, spaces between solid particles, which reduces the infiltration of air and water throughout the soil (Patric & Helvey, 1986). This was particularly reported among forested grazing within steep ranges and in incidences with intensive livestock grazing (Chandler, 1940; Sluder, 1958; Stoeckeler, 1959;

Linnartz et al., 1966). Following a hardwood grazing study in New York, Chandler (1940) noted the reduced percentage of aggregates within grazed versus ungrazed soils. This reduction was attributed to tightly packed soils with reduced pore space and increased soil volume weight. Chandler (1940) suggested several factors could have influenced the higher soil volume weight, with livestock trampling possibly impacting soil compaction. Stoeckeler (1959) also reported livestock trampling within Wisconsin oak and pine woods considerably reduced infiltration rates and increased soil density. Moreover, Linnartz (1966) presented similar findings to support intensive grazing causing increased soil density, reduced infiltration rates, and slowing the movement of water through forested soils.

Ongoing compaction leads to difficulty for feeder roots (fine, non-woody roots) to penetrate topsoil to procure, absorb, and transport water and mineral nutrients to tree roots below. As soil compaction increases, rainwater becomes unable to permeate the topsoil, remaining on the surface, making susceptible to erosion with the loss of water and organic matter (Diller, 1935; Chandler, 1940; Linnartz, 1966; Patric & Helvey, 1986). Additionally, erosion occurs as livestock can speed up the decomposition rate of leaf litter, the layer of dead plant material on the soil surface. Historical studies have reported that the accumulation of leaf litter, necessary to promote germination and the survival of tree seedlings, is reduced by livestock trampling (Diller, 1935). The continued trampling of livestock increases the rate of decomposition and eventually causes destruction of the protective humus, organic material that forms in soils upon plant and animal matter decay. This exposes the bare soil to dryness, degradation, and erosion (Williams, 1951; Belsky & Blumenthal, 2002). Moreover, soil compaction and erosion reduce the availability of nutrients and plant material, which creates non-natural drought-like conditions that stress trees, reduces tree stand health and limits forest productivity (Belsky & Blumenthal, 2002).

Livestock grazing behavior within forest has been shown to inadvertently lead to root injuries, which can allow entry points for pathogens (Hawley & Stickel, 1948; DeWitt, 1989). These pathogens from decay organisms cause the staining of wood called mineral stains that can lower the price of the wood for timber products (Williams, 1951). Also, livestock has been shown to aid in the damage to tree seedlings and saplings, necessary to germinate and occupy the forest floor (Schmidt & Hansen, 1998). This damage occurs by livestock browsing and trampling, reducing the potential of tree regrowth and increasing competition for undesirable species (Hawley & Stickel, 1948; DeWitt, 1989). A study evaluating grazed and ungrazed forests in Kansas characterized grazed forests as having lower site quality that diminished the productivity for regeneration of desired hardwood species. Schmidt & Hansen (1998) reported that grazed forests tended to have higher levels of eastern redcedar regeneration (*Juniperus virginiana* L.) and lower levels of regeneration for preferred hardwood species (Schmidt & Hansen, 1998). Though direct causations were unable to be made between forest stand conditions and grazing, these findings suggested, which forest were more likely to have been grazed based on conditions presented.

Prolonged overgrazing of the forests can eventually cause physical damage to larger trees that results in a decrease in timber growth rate and increase of mortality rates with crown die-back and rotten wood (Hawley & Stickel, 1948). This continuous interruption of the natural forests' cycles impacts the ecosystem by causing a decrease in tree species richness, disruption for forest regeneration, and transformation of the forest stand (Hawley & Stickel, 1948; Schmidt & Hansen, 1998; Belsky & Blumenthal, 2002). Furthermore, the changes in forest competition yields an increase in competition for food (ground vegetation), habitat (nesting and escape cover), and water that impacts the abundance of vertebrate animals and reduced wildlife diversity (Fleischner, 1994).

Due to these negative impacts, agriculturalists and foresters have become wary of pasturing livestock within forests. Campaigns were developed during the post-war era to persuade farmers to change practices and exclude livestock from woodlands (Williams, 1951; McQuilkin & Scholten, 1989). For a time, the practice of woodland pasturing became less abundant, and between 1946 – 1954 there had been little information published on the pasturing of farm woodlands. Though forests were repurposed for industrial activities (e.g., high grading, wood production) and diminished by clearing for agricultural purposes and pasturelands. This has persisted leaving individual trees, small groves, or unmanaged forests as remnants of the original landscape.

Intensification of Agriculture and Conventional Livestock Grazing

Towards the beginning of the 20th century, agricultural production began to consolidate towards industrialized systems to meet the growing demand for food crops and animal protein. Initially, this contributed to the dramatic growth of livestock numbers in the U.S., which coupled with overstocking, unregulated grazing, and extreme climatic events led to the deterioration of private and public grazing lands (Sheridan, 1981; Coughenour, 1991; Fleischner, 1994; Krueger et al., 2022). Eventually, through the development of technologies and regulations to reduce these widespread impacts, farmers and ranchers began to apply continuous grazing pressure on localized areas. This practice is known as continuous grazing, permitting livestock unrestricted access to forage within a specific unit of land (Vallentine, 2000; Allen et al., 2011).

Continuous grazing became common because it allowed for low input cost (i.e., fencing), minimal daily management requirements and decent animal gains with adequate stocking rates (Kothmann, 2009; Rayburn, 2014). Reviews have also shown this method can be effective compared to intermittent grazing systems, during periods of plentiful forage availability, within rangeland systems, and for animals with moderate to low maintenance requirements (i.e., dry cows, bred heifers, beef cows) (Heady, 1961; Norton, 1998; Holechek et al., 1999; Rayburn, 2014). This open-grazing system presents the opportunity for livestock to graze forage more selectively, with liberty on the frequency and intensity of grazing within a particular area. Such grazing behavior has shown to be impacted by factors influencing the preference for higher-quality forage, limiting grazing distance to water sources, and avoiding excessive exertion for nutrient intake (Bailey et al., 1996). Over time, this can cause concentrated grazing areas within proximity to water points and desired forage patches (Teague & Dowhower, 2003). This becomes more common within larger grazing spaces with varied terrains and conditions leading to spatial patterns of heavily grazed and lightly grazed to ungrazed areas (Bailey et al., 1996).

Following a study in Texas, Teague & Dowhower (2003) reported incidences of more bare ground and less herbaceous basal area for desired species among continuous grazing compared to rotational grazing. Another study by Teague et al. (2011) showed similar responses for light and heavy continuous grazing compared to intermittent grazing system, in which continuous grazing tended to increase the percentage of undesirable forage and bare ground. This provokes degradation of the soil and deterioration of vegetation because preferred plants are repeatedly grazed receiving inadequate rest between grazing periods. Forages capable of withstanding this stress outcompete grasses and forbs vulnerable to damaging conditions. Consequently, pastures become monocultured and susceptible to growth of unfavorable and invasive species, resulting in adverse grazing conditions.

Furthermore, continuous grazing has shown to negatively contribute to impacts on the environment and ecological sustainability. This is through greenhouse gas emissions, unsustainable land usage, degradation of landscapes and natural resources, and loss of biodiversity (Fleischner, 1994; Chaikina & Ruckstuhl, 2006; Krausman et al., 2009; Herrero et al., 2015; Grossi et al., 2019). For instance, studies have reported livestock farming activities are estimated to generate nearly 15% of the total global greenhouse emissions (GHG) including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), further contributing to land use change, landscape degradation, and biodiversity loss (Herrero et al., 2015; Grossi et al., 2019). This link to greenhouse gas emissions, in particular enteric fermentation, and other environmental impacts has enhanced efforts in reducing natural resource usage while increasing grazing efficiency; by transitioning to more sustainable grazing practices (Herrero et al., 2015).

This includes promoting conservation practices such as rotational grazing, a conservation practice that helps in pasture recovery by moving livestock strategically between grass pastures (Vendramini & Sollenberger, 2007; Rayburn, 2014). Research into the effectiveness of rotational grazing compared to continuous grazing has been conflicting, though endeavors continue in promoting rotational grazing and other grazing systems that reduce ecological impacts and improve efficiency of livestock production (Heady, 1961; Matthews et al., 1994; Holechek et al., 1999; Teague & Downhower, 2003; Briske et al., 2011). This warrants the further endorsement of integrated grazing systems that facilitate the implementation of grazing and climate-smart practices. Such as agroforestry systems that allow natural resource management, landscape restoration, and mitigation of greenhouse gas emissions towards sustainable agricultural livestock production (Elevitch et al., 2018; Mahmud et al., 2020).

Modern Silvopasture: An Agroforestry Practice and Adaptive Strategy

Agroforestry Practices

Indigenous agroforestry systems (AFS) are described as ancient technologies practiced from traditional ecological knowledge (TEK) to integrate agricultural production and natural resource management in various forms (Deneven et al. 1984; Eden & Andrade, 1987; Kang & Akinnifesi, 2000; Miller & Nair, 2006; Dagar, 2016; Nair et al., 2017; Heming et al., 2022). These systems facilitated the implementation of traditional land-management practices including growing trees, integrating trees and shrubs with farming crops, and managing livestock in specific regions (Deneven et al. 1984; Eden & Andrade, 1987; Nair et al. 2017). Within the late 1970s, these concepts would become institutionalized mainly in tropical regions as 'modern agroforestry', with principles defining the system as being intentional, integrative, and intensive (Kang & Akinnifesi, 2000; Tejwani, 2008; Dagar, 2016; Elevitch et al., 2018). Between the 1980s and 1990s, these principles were transformed into modern agricultural systems and technologies, known as contemporary agroforestry practices (Dagar, 2016; Nair et al. 2017). This new age definition of agroforestry encompassed the intentional integration of trees, crops, and/or animals to help diversify and sustain production of agricultural commodities (Nair et al. 2017). The integration of such components bridges the gap between agricultural production and natural resource management through the practices of alley cropping, forest farming, riparian forest buffers, windbreaks, and silvopasture (Elevitch et al., 2018; Clason and Sharrow, 2000).

Temperate Silvopastre Systems: Plantation and Woodland Grazing Systems

Silvopasture combines the concepts of silviculture, forage management, and livestock husbandry (Clason & Sharrow, 2000; Fike, 2014; Jose & Dollinger, 2019). This involves synergistic designing (spatial and temporal), balancing ecological principles, and management of grazing systems and forestry components to generate products and provision ecosystem services to meet human goals and objectives (Jose et al., 2004; Jose & Dollinger, 2019). Within temperate agroforestry, there are two main types of silvopasture – plantation, the introduction of trees into an open pasture, and woodland, the thinning of trees and planting of forage for livestock grazing [i.e., modifying natural forests and woodlands through thinning to develop forage plants in the understory] (Brantly, 2014; Gabriel, 2018). Research has demonstrated that the combination of tree, forage, and livestock interactions can be managed to provide a multitude of tangible and intangible environmental, economic, production, and social benefits for supporting sustainable livestock farming and natural resource management (Clason & Sharrow, 2000; Varsha et al., 2017; Aryal et al., 2019; Jose & Dollinger, 2019; Shi & Conway-Anderson, 2022).

Ecological and Environmental Benefits

A primary ecological benefit of silvopasture is ecosystem services, which impact soil health and biodiversity through the regeneration of soil and organic matter within bacteria-dominated pastures and fungi-dominated trees (Sharrow & Ismail, 2004; Rolo et al., 2023). Plantation silvopasture has shown to impact organic matter and soil microbial biomass carbon within mid-aged tree stands compared to open pastures (Poudel et al., 2022). Haile et al. 2008) also reported plantation silvopasture systems had increased soil organic carbon compared to open pasture areas. This suggests the amount of organic matter could increase in pasture by regenerating bacteria-dominated soils associated with tree growth. The roots of trees will develop and gain the ability to stabilize the soil and improve soil drainage. Furthermore, dependent on the tree selection, the roots will begin to fix nitrogen and enhance soil health and fertility, especially of formerly degraded ecosystems (Clason & Sharrow, 2000; Chedzoy & Smallidge, 2011). Moreover, soil fertilization will be further supplemented by the dispersal of manure deposits from integration of managed livestock grazing to potentially support tree growth, promote favorable conditions for existing vegetation, and facilitate biodiversity (Kallenbach et al., 2006; Rigueiro-Rodríguez et al., 2011; Jose & Dollinger, 2019). Over time, the capacity of young trees will expand to capture, absorb, and store atmospheric carbon dioxide for carbon sequestration, an effect shown to be greater when trees are planted on marginal land in conjunction with livestock grazing (Nair et al., 2009; Howlett et al., 2011; Aryal et al., 2019**)**.

Even at a younger age, trees within plantation silvopasture will enhance biodiversity by creating habitat and food source availability for pollinators and wildlife species (Perez-Alvarez et al., 2023; Rigueiro-Rodríguez et al., 2011). Birds and invertebrates have been documented to increase in species richness and abundance within silvopastoral systems (McAdam et al., 2007; Broom et al., 2013). A case study of an intensive silvopasture in Colombia reported a plantation silvopasture with *Eucalyptus spp.* and *Leucaena leucocephala* that provided ecosystem services such as bird biodiversity, as well as tick control, nitrogen fixation and carbon sequestration

(Broom et al., 2013; Kremen**,** 2020). Also, the system was shown to reduce methane production and land use for livestock production while enhancing meat and milk production (Kremen, 2020). Similar to plantation silvopasture focused on creating habitats, woodland silvopasture can facilitate the restoration of fungi dominated soils, forested areas, and wildlife habitats. This aligns with the interests of natural resource and conservation professionals to influence the management of restored habitats for wildlife and aquatics. An example is the efforts towards savanna and woodland restoration to support biodiversity among mammals, birds, amphibians, and invertebrates that depend on these ecosystems. With savanna and woodlands restoration from an existing treed landscape, forage could become more available as the stand is thinned. Such conditions have been reported to increase and diversify vegetation production with continuous opening of forest canopies (Conroy et al., 1982; Peitz et al., 2001; Lindgren & Sullivan, 2013).

Economic & Production Benefits

Beyond ecological and environmental benefits, silvopasture throughout various tree management stages has the opportunity to diversify revenue with the production of commodity products (Jose & Dollinger, 2019). Younger trees within plantation silvopasture can be used within intercropping practices as a strategy to increase agricultural and economic productivity, compared to monoculture sites (Vandermeer, 1995). While timber trees need time to grow to reach productive height, the landowner can amplify production of multiple products among fast-growing fruit and fodder trees without significant economic risk. For instance, plum trees can bear fruit within three to six years, along with apricots, cherries, apples, and persimmons. This can allow for a constant flow of fruit yield, diverse food sources, and livestock products (e.g., chickens, sheep) as the components require different imports, tend to share few diseases and pests, and target varied local, national, and global markets. Dávila-Solarte (et al. 2019) studied the performance and economic return of sheep grazing within a coffee plantation, reporting higher daily weight gain among the sheep that grazed within the coffee plantation. Also showed reduced use of herbicides and chemical fertilizers which resulted in greater utility of the operation with a higher net profit per acre.

Intensive grazing management within silvopasture systems can benefit tree stand management, reduce the time required to produce high-value timber products, and attain a shorter return on investment with timber products (Lemus, 2023). Economically, landowners will decrease inputs for pasture (i.e., chemical fertilizers), gain higher economic returns from commercial timber production (e.g. rot-resistant fence posts); fruit and tree nut, and other food (e.g., maple syrup) products, and secure additional income to livestock production (Klopfenstein et al., 1997; Garrett et al., 2004). Long-term landowners have the potential to harvest and produce value added products (e.g. cider), expand the operations financial portfolio, and seize tax benefits.

Mature trees have the additional long-term benefit of providing uniform shade and shelter for livestock, and positively impacting livestock productivity (Hawke & Dodd, 2003; Garrett et al., 2004; Jose et al., 2019; Wilkens et al., 2022a). Shade within silvopasture creates a cooler environment than open pastures which reduces heat stress, decreases water and energy loss, increases foraging time, extends forage availability, and improves forage nutritive value (Kallenbach et al., 2006; Kallenbach, 2009; Yadav et al., 2019; Smith et al., 2022). This can control high temperatures and humidity combined with alkaloids produced by endophyte-infected tall fescue, which increases the animal's susceptibility to heat stress. As summer temperatures are rising and weather has become more erratic, the near availability of shade, in the summer (i.e., high humidity, direct sunlight), and shelter, in the winter can support resilience among operations (Kallenbach, et al. 2009). Livestock can utilize shade, to reduce heat stress, which results in increased livestock performance such as higher milk production and greater weight gain (McIlvain and Shoop, 1971; Fike et al., 2004; Karki & Goodman, 2010; Brantly, 2013; Pent & Fike, 2018).

Kendall (et al. 2006) showed the impact of provisioning shade to Holstein Friesian dairy cows, in which cows with access to artificial shade had higher milk production than cows that had no access to shade. The study also discussed the concept of cows displaying behavioral stages to stand underneath shade instead of lying down, behavior shown among livestock with access to shade (Kendall et al., 2006; Tucker et al., 2007). This was also shown in studies that indicated the presence of shade could optimize time spent grazing and thus impact livestock productivity (Karki & Goodman, 2010; Kendall et al., 2006). The distribution of natural shade from trees in silvopasture compared to artificially manufactured shade or open pasture facilitates the reduction of stress under extreme temperatures but also minimizes the crowding around isolated shade trees (McDaniel & Roark, 1956). Additionally, livestock grazing within silvopasture can provide shelter from precipitation and reduction in wind speed to off cold weather effects on animal health and performance (Kallenbach, 2009). Cold and wet weather mixed with wind can cause cold stress, which will increase nutrient requirements for maintenance as animals regulate their body temperature (Young, 1983). If nutrient deficiency escalates, the result can be a decline in livestock performance. This becomes of concern during spring calving season when the weather can consist of excess rain with wind (Mercker & Smith, 2019).

Another production benefit of developing and managing a silvopasture system is the creation of a microclimate condition. This can benefit forage, livestock, and wildlife by reducing temperature under the canopy, slowing wind speed, provisioning shade, and decreasing solar radiation. Forage grown within the microclimate have the potential to be maximized by forage diversity, production, and nutritive value. Though woodland forage production is estimated to be lower than improved pastures, the forage within shaded conditions tends to have increased nutrient content (Holechek et al., 1981; McQuilkin & Scholten, 1989; Kephart & Braxton, 1993; Varsha et al., 2017). Ford (2019) executed a comparative open pasture, silvopastoral, and woodland grazing study in Minnesota where the silvopastoral system produced greater forage production than the woodland grazing system and increased in forage nutritive value compared to the open pasture and woodland system. This study highlights the high nutritive value capability, but also the potential productivity of these forages when paired with an open pasture system, especially in drought conditions.

Furthermore, within tree stands, atmospheric temperatures can be several degrees cooler than in open pastures. These conditions are favorable to cool-season (C_3) grasses that have been shown to be more resilient to shade than warm-season (C_4) grasses (Lin et al., 1999; Lin et al., 2001; Pang et al., 2019a; Pang et al., 2019b). Cool-season grass growth can be extended into mid-summer and support nutritional demand of livestock and combined with warm-season grasses and fodder to develop a diversified diet (Garrett et al., 2004; Kallenbach, et al. 2009; Chezdoy and Smallidge 2011; Pent & Fike, 2018). Overall, this supplies additional grazing opportunities, expands acreage for production, aids in alleviation of pressure on pastures, and reduces livestock feed cost. Forage within pastures can be conserved by allowing longer rest periods within drought periods without decreasing productivity, ultimately improving whole farm management. Moreover, the practice can lead to an extension of the grazing capacity with research showing the potential of grazing forage within tree stands as a viable production practice. Kallebach (2009) reported that forage growth began earlier in the spring and continued longer in the summer and later autumn in the integrated treatment allowing more days of direct harvesting from grazing animals and reduction in the need to make and feed stored forage.

Social and Socioeconomic Benefits

Such a system also provides social benefits of social responsibility (i.e., with consumer interests in animal welfare) and aesthetics. Though intangible, have been discussed to aid in marketability among consumers and stewardship in sustainable production in agricultural land use and natural resource management (Clason & Sharrow, 2000). Specifically, through the management of tree and wood stands producers have the potential to change the aesthetic and recreational value of woodlands by diversifying and increasing the abundance of wildlife and flowering plant populations and modification or loss of aquatic habitat. Additionally, the development of these systems supports the resilience to climate change and agricultural production (Shi & Conway-Anderson, 2022). This ideally allows less environmental damage than monocrops and intensive livestock production. Moreover, these systems further promote ecosystem services to include improved water quality and watershed characteristics, pollution abatement, mitigating erosion and nutrient-rich runoff.

Components of Silvopasture Establishment and Management

Plantation silvopasture, the establishment of trees within existing pastureland, involves the design of tree species selection arrangement within the pasture (Robinson & Clason, 2000; Nowak et al., 2003). To develop a plantation silvopasture, the landowner will develop a plan for establishment of desired tree species to include modification of farm management practices, site preparation, tree planting, and protection. These steps aim to support the survival, establishment, and growth of the trees by reducing competition for resources (i.e., light, nutrients, water) and minimizing damage from livestock and machinery. Among the types of silvopasture, this method of establishment has been encouraged because the integration of livestock into forested areas has typically been discouraged due to ecological risks. As trees are introduced into the pasture, the landowner eliminates the cost of forage establishment, requirement to control brush, and necessary removal of timber harvest residues. However, according to research, woodland silvopasture, the thinning of trees and planting of forage for livestock grazing, has become the preferred method for silvopasture establishment (Wilkens et al., 2022b). As plantation silvopasture requires a significant tree establishment and growth phase for landowners to observe long-term benefits. Woodland silvopasture involves the integration of woodland, forage, and livestock management through the modification of pre-existing forests and/or closed woodland canopies through thinning and fire management to open stands (Brantly, 2014; Gabriel, 2018).

Woodland Management

Woodland silvopasture requires gradual establishment and continuous management of the forest stand. Similar processes for establishment and management of woodland silvopasture are comparative to applications towards savanna and woodland ecosystem restoration (McCarty, 1998; Nelson, 2004; Dey et al., 2017). This establishment involves a stepwise process towards opening the canopy, clearing the midstory, and constant management for subsequent forage establishment (Chezdoy and Smallidge 2011; Brantly, 2014; Dey et al., 2017; Gabriel, 2018).

Initial clearing of the forest stand usually involves mechanical or chemical thinning, and/or commercial timber harvesting, with subsequent elimination of the brush (i.e., shrubs and saplings). Thinning for restoration strategies usually consist of reducing the basal area to restore the natural community structure and composition (Nelson & Studyvin, 2008). Such thinning strategies are applicable for the establishment of woodland silvopasture, with modifications to obtain basal areas for conditions to support forage establishment. To facilitate the target basal area and stand structure, it is suggested to assess the stands historical conditions, observe conditions of the existing system and obtain knowledge of the physiological threshold for survival growth and reproduction (Dey et al., 2017; Hanberry et al., 2017). Aid guides such as stocking charts and crown cover charts have been shown to be effective in assessing the abundance and density for thinning and determining management standards for overstory trees (Dey et al., 2017; Hanberry et al., 2017). This process in achieving a desired basal area requires thinning over time to prevent stand damage and reducing competition for invasive species (Nelson & Studyvin, 2008). For example, Nelson & Studyvin (2008) suggested starting to reduce a basal area of 120-150ft^2/acre to 70-80ft^2/acre by thinning, followed by prescribed burn at 3-4 intervals and secondary thinning to 30-50 ft^2/acre after ten years.

Following thinning or harvesting, it is essential to clear the midstory of the stand during the establishment stage. Common methods for midstory tree removal are chemical application and mechanical removal (Lhotka et al., 2023). Restoration studies have also examined various ways of opening the midstory by eliminating shrubs and saplings through burning and managed grazing (Chezdoy & Smallidge, 2011). This was suggested by Harrington and Kathol (2009) in using managed cattle grazing in combination with fire. Though aspects of the combination need to be investigated further to account for grazing intervals to support herbaceous growth, quarantine to reduce the introduction of exotic species, and frequency of fire (Nelson, 2004; Harrington & Kathol, 2009). Reports have also indicated livestock exclusively can be used strategically as a cost-effective method to control brush and vegetation and minimize the abundance of invasive species (Dostálek & Frantík, 2008; Chezdoy & Smallidge, 2011; Hart, 2011). Goats have demonstrated capability in eliminating brush and converting unwanted vegetation into saleable products (Hart, 2021; McCue, 2022). This species also has shown a hardiness in consuming toxic plant species, commonly found in forest stands. Livestock can also be used to maintain the openness of the midstory while the canopy is further increased as closed canopies tend to lack ignitable material for effective use of fire (Harrington & Kathol, 2009). This also assists in reducing competition between trees and plants for nutrients and promoting stand health (Merker & Smith, 2019). Moreover, the inclusion of livestock aids in recycling nutrients through feces and urine deposits.

Fire is used to support the reviving plant species in competition from introduced and non-fire adapted species (McCarty, 1998; Dey et al., 2017). To support this function of redeveloping the plant community, fire is utilized as a tool to aid in opening the midstory, removing excessive litter, preparation of the seedbed, and management of oak seedlings. Ongoing fire management after the canopy and midstory has been opened will increase the light availability for the understory. This can initiate growth of the herbaceous groundcover and impact future production and quality of native and suppressed plant species.

Forage Establishment and Management

Forage establishment is critical to ensuring the access of food for grazing and browsing animals. Tropical grazing and agroforestry systems have long incorporated the utilization of indigenous and exotic fodder trees as an additional forage source, which can be applied, especially within (plantation silvopasture systems). Fodder trees are known to provide advantages for animal production by offering feedstuffs that are high in protein, minerals, and digestibility (Paterson et al., 1998). Also, fodder trees have shown to be tolerant within various management practices, and useful for producers during dormancy of other sources of food and within harsh climate conditions (Paterson et al., 1998). Like trees species, attention is required as fodder trees contain antinutritive factors, polyphenolics, toxic amino acids, cyanogenic glycosides and alkaloids that can impact palatability, digestibility, and toxicity to livestock (Paterson et al., 1998).

The relationship between overstory trees and forage production and quality is affected by aboveground and belowground interactions that cause competition for resources - light, nutrients, and water (Moreno et al., 2013). Light intensity and solar radiation impacted by overstory tree species and composition can affect the growth and reproduction of forage species (Hart & Chen, 2006; Valladares et al., 2016). Light, usually full sunlight is required by plants for photosynthesis to convert energy to grow, develop, and reproduce. Light intensity has shown to be proportionally affected by canopy cover of overstory trees; as the percentage of canopy cover increases the intensity of light decreases below saturation level requirements of the plants and leads to decline in production (Krueger, 1981). To minimize a decrease in forage growth it is recommended to maintain canopy cover of about 25 – 50% for warm season grasses and 35-60% for cool season grasses. Though literature has estimated that a reduction in forage yield occurs around 20-30% canopy cover (Krueger, 1981).

Additionally, plants will use photosynthetically active radiation (PAR), the wavelengths of light within 400-700 nm of the light spectrum, to facilitate chemical process for photosynthesis. Overstory trees with a higher percentage of canopy cover will inhibit the amount of light and intercept PAR, reducing the light rays available for understory plant species (McCrady & Jokela, 1998; Dey et al., 2017). The degree of inhibition and interception is dependent on the overstory trees species type. Krueger (1981) articulates how deciduous tree canopies reduce the proportion of red and blue light rays, which are the most photosynthetically active, which enriched light rays related to cell elongation and control of plant hormones to induce morphological changes such as flowering. Also, Krueger states that coniferous tree canopies affect light quality similarly while filtering less of the red light. Krueger infers that light quality has minimal influence on presence or absence of plant species; but influence physiological and morphological characteristics of the plants thus attribute to nutritional value (Krueger, 1981). The change in light intensity and solar radiation can be affected by overstory tree species composition, but also, stand conditions and landscape structure. Kolb (2006) shows with a diagram that tree species on different positions of slope can influence the amount of direct sunlight exposure, percentage of light intercepted by tree crown, and light intensity for the plant species. These factors can also be influenced by the site of plant species under the canopy or adjacent (Monreno et al., 2007).

Besides light, the presence of overstory trees affect nutrient and water availability, creating competition for these resources. Overstory trees tend to compete more efficiently for belowground nutrients and water than understory plants (Moreno, 2013). However, the presence of trees can modify soil physical properties and positively impacts the nutrients under the canopy (Marañón, et al., 2009). This has been reported with the higher content of N and K nutrients found under the canopy that can be beneficial for various plant species (Frost & Edinger, 1991; Moreno, 2013). An increase in soil nutrients underneath the canopy can also be attributed to livestock attracted to shade and redistribute nutrients thar enrich the soil for plant species. Water becomes the primary limiting factor in overstory trees and understory plant interactions as trees will intercept a high proportion of rainfall leaving the tree understory between 5 – 50% less than the overstory (Marañón, et al., 2009). This percentage typically remains lower during hotter periods of the year when temperatures and evapotranspiration increase. Less evaporation tends to occur in tree canopy microclimates than open areas; causes the under canopies to be cooler, maintain a higher relative humidity, and reduce evaporative stress on forage species (Frost & McDougald, 1989; Moreno et al., 2013). Within the colder months, the temperature under the canopy tends to be warmer, which allows continued growth throughout the fall to winter months.

Overstory tree structure and management can change the forage production and quality of the understory herbaceous community (Lissbrant, 2005; Marañón, et al., 2009). The conditions for optimal forage production and quality also depend on the adaptability of the plant species to various tree species-stand conditions (Jose et al., 2004; Valladares et al., 2016). For instance, cool-season grasses (C_3) tend to be more shade-tolerant than warm season grasses (C_4) which thrive in conditions with direct sunlight (Lin et al., 1999; Bernardi et al., 2016).

Cool-season grasses will grow in the spring and late in fall, as they are more suited for cooler seasons and have been shown to be shade-tolerant. As these plant species can be shade tolerant, tend to be more prevalent within the understory of the forest stand. Krueger (1981) highlights that cool season grasses are adapted to grow in open areas reaching saturation of light for photosynthesis around 20% and similarly adapted to shaded environments with saturation level of 10%. Their shade tolerance has been found to be focused within late summer and early fall, which makes them ideal for inclusion in multi-species forage systems (Lin et al., 1999). These species such as orchardgrass (*Dacrylis glomerata*) and smooth bromegrass have the potential to be utilized in transformative overstory tree-forage systems to increase forage production and maintain animal performance. Within the Lin (et al., 1999) study, smooth bromegrass (*Bromus inermis*) was shown to have a significant increase in mean dry weights under 50% shade compared to exposure of full sun.

A study in eastern Nebraska examined the effect of an introduced cool-season (smooth bromegrass), native warm-season (big bluestem), and introduced legume (birdsfoot trefoil with overstory leaf area index (LAI) and understory light transmittance (LT) under Scotch pine (*Pinus sylvestris L.*) and green ash (*Fraxinus pennsylvancia* Marsh.) (Perry et al. 2009). Like the previous study, Perry (et al. 2009) reported a higher incidence of smooth bromegrass to increase in forage yields and crude protein as LAI decreased and LT increased. Also, big bluestem (*Andropogon geradii*), a warm season remained productive under partial shading (20-75%), though it doubled in performance with full sunlight. The legume species birdsfoot trefoil (*Lotus corniculatus*), however, tended to produce low yields at LT levels below 75% (Perry et al., 2009). Though, in a comparable study, legume species tended to increase under 50% and 80% shade (Lin et al., 1999). This highlights consideration of shade tolerance among legume species and inclusion beneath overstory trees.

Barriers and Establishment to Adoption of Silvopasture in Tropical and Temperate Systems

Though observed and potential benefits of silvopasture have been noted, there has been a varied response in the increase in the adoption of the practice due to a range of factors within tropical and temperate environments. Research studies have shown that silvopasture is increasing in popularity (Mayerfeld et al., 2016; Wilkens et al., 2022a; Wilkens et al., 2022b; Asbjornsen, 2023; Mayerfeld, 2023), though the practice is still not widely adopted. This is due to a variety of technical, financial, policy and cultural barriers.

Barriers to the adoption of silvopasture systems vary from willingness to engage in practice to minimal knowledge base for implementation. Plantation silvopasture has been promoted to include trees within open pastures because of reduced input costs and potential to increase farm productivity. Though studies have reported the establishment of trees within farms as a challenge in farmer decision-making (Ambrose-Oji et al., 2022). Neumann et al. (2007) assessed the willingness of farmers in Alberta, Canada to establish tree plantations within previously cleared farmland. They reported a general opposition to incorporating trees within farmland due to valuation of family farming (Neumann et al., 2007). Though studies are limited in direct assessment of the valuation of pastureland, similar connections can be made as another challenge to plantation silvopasture is the forfeit of pasture for trees. A mixed method survey among livestock producers in Virginia showed over half of producers were uninterested in planting trees to establish silvopasture, with forfeiting pasture to be the most identified constraint to plantation silvopasture (Wilkens et al., 2022b).

Studies for producer and natural resource professionals' perceptions of silvopasture practices have shown an unawareness or gap in knowledge (Ford et al., 2021). This has been complicated by the limited capacity to disseminate information and lack of examples (i.e., demonstration sites) showcasing silvopasture practices. Such an issue with technical knowledge transfer results in uninformed and inexperienced producers of silvopasture components and applications (i.e., design, development, execution). Ultimately this leads to mismanagement or avoidance in adopting the practice. Because producers can be naïve to silvopasture system technical standards there is the risk of unsuitable establishment or management strategies (Ford et al., 2021). This can include improper design and consideration for planting trees, neglecting dimensions required for farming operations and land maintenance or default of woodland management (Mayerfeld et al., 2023). Ford et al. (2021) concluded that there is a need for more educational programming that expands the knowledge of and provides technical assistance to landowners and natural professionals.

Financial barriers and challenges associated with the establishment and management of silvopasture have been documented within a few studies impacting the adoption or cease of this practice (Shrestha et al., 2004; Frey et al., 2012; Lee et al., 2020; Wilkens et al., 2022a; Mazaroli et al., 2024). This was common mainly among establishment and/or management of plantation silvopasture systems, probably because this system is most widely initiated compared to woodland silvopasture. To establish plantation silvopasture, upfront costs and labor are required primarily to plant and protect trees (Lehmkuhler et al., 2003). Ideally, the economic return opportunities can offset these initial investments, though the time between establishment and return on investment can deter potential adopters (Shrestha et al., 2004; Kumawat et al., 2014; Lee et al., 2020).

An Argentina study reported a change in perceptions among silvopasture adopters, years following practice implementation (Frey et al., 2012). This study found that adopters' perception of economic return benefits decreased over time, especially among cattle ranchers and annual cash croppers. Adopters also indicated a reduction in the belief that government subsidies provided an advantage of the practice (Frey et al., 2012). These changes in benefit perceptions, in addition to cost inputs related to the systems were likely to impact discontinuance of silvopasture systems (Frey et al., 2012). Shrestha (et al., 2004) also reported concerns linked to cost and government assistance hindrances to silvopasture adoption using a strength, weaknesses, and opportunities (SWOT) approach. Among Florida participants with experience in silvopasture, the long-term investment required for silvopasture was consistently indicated as a weakness for the practice (Shrestha et al., 2004). Participants also considered uncertain governmental regulation as a threat to silvopasture adoption.

Similar issues with governmental assistance were raised during a study conducted in California (Mazaroli et al., 2024). Among existing silvopasture producers, Mazaroli (et al., 2024) noted producers were financially able to self-fund their respective silvopasture systems. Though the scalability of these systems were constrained due to limited funding mechanisms for additional labor requirements required with tree planting. The cost specifically required for planting trees within farms with animals has been shown to be a challenge (Lee et al., 2020; Mazaroli, 2024). Silvopasture adopters and non-adopters in Colombia expressed concerns around the high financial investment due to maintaining planted trees during the initial phase (Lee et al., 2020). Also, study participants indicated issues with investment for protecting trees. This financial cost is due to the risk of damage to planted seedings and young trees by livestock and wildlife browsing, which requires protection to ensure adequate survival. Lee (et al., 2020) reported silvopasture adopters mainly expressed concerns about time and labor of protecting trees against cattle. California producers indicated funding sources like cost-share funding available to support cost associated with establishing trees (Mazaroli et al., 2024). However, producers mentioned significant gaps remained between cost-share funding and the actual cost in tree planting, care, and protection.

Compared to the economic requirements of plantation silvopasture, there are various financial, time, and labor investments necessary for proper implementation of woodland silvopasture. These investments occur during the establishment process, with financial cost necessary for thinning, brush removal, burning, and forage seeding. Also, these costs incur throughout management of the system. Studies have reported financial and labor strain linked to the conversion of pre-existing stands (Wilkens et al., 2022b). These costs can be dependent on existing stand conditions, and impacted by weather damage, access to resources and landowner goals and objectives. Upfront establishment and maintenance costs can be significant for woodland silvopasture, though a suspected trade-off is the time between establishment and economic return. For instance, depending on the tree stand condition, thinning and harvesting are able to offset establishment costs and provide landowners with the opportunity to market value timber products. Landowners also could capitalize on woody biomass markets for low-grade timber and low-quality trees including firewood, pulp, and chips. Additional barriers and challenges mentioned to impact silvopasture adoptions are land tenure and ownership. This has shown to be especially apparent among new and beginning landowners and minority groups (Smith et al., 2022).

Historical Perceptions: Barrier of Woodland Silvopasture Adoption

A persistent challenge to the adoption of woodland silvopasture especially, has been the historical bias among foresters that livestock cause significant damage to wooded areas. Such bias has significantly impacted the implementation of woodland silvopasture. With opposition for integration of forestry and livestock production, a less managed form of forest grazing developed shown to damage tree stands by browsing and trampling seedlings, compaction, and mortality among larger trees (Den & Dey, 1934). Furthermore, adversely affected timber value and forage yields (Ford, 2019). This is directed more towards the terms of wooded livestock paddocks, pasturing woods, and woodland grazing that have been attributed to silvopasture. Over time, campaigns to exclude livestock from the woodlands prolonged advisements to avoid the inclusion of livestock grazing among trees (Abbott, 1954). These advisements have turned biases among agricultural and natural resource professionals against livestock and trees and limited the resource base for assistance to management for woodland silvopasture (Orefice & Carroll, 2017). This has led to a limitation of information and prolonged lack of technical assistance among both silvopasture systems (Stutzman et al., 2019). To include a lack of technical assistance to farmers to adapt the system to specific local conditions.

Conclusion

Societies' land use and natural resource management surrounding key periods of agricultural establishment, production, and human development was traced to explore how human-environmental interactions have influenced traditional management practices. This also seeks to characterize humans' dependence, adaptation, and modification of the landscape. By reviewing historical literature of early civilizations, this review shows the transition from subsistence livelihoods towards the production of agricultural and forestry products, and subsequent change in human land use from management towards resource harvesting to meet demands of the growing population. This was most apparent during the period of colonization, in which European colonies leveraged Indigenous groups' knowledge, exploited natural resources and landscapes for economic gain and further population development. Ever since an imbalance between ecological sustainability and productivity, particularly among livestock production has persisted domestically and globally.

This imbalance has been exasperated by population growth, industrialization, human behavior and production activities with natural resources, and climate change. This has changed throughout human advancement and progression with demand of intensive livestock systems for consumption and survival against the management of natural resources. Presently, this imbalance has shown to significantly impact land use, resource availability, biodiversity, and productivity of agriculture, thus warranting research into adaptive strategies that would mitigate and establish balance between livestock production and natural resource management and ensure sustainability of landscapes. To ensure resilience of agricultural systems, researchers have posed the modification and adoption of traditional management practices once found to maintain balance of ecological sustainability and productivity. Amongst these practices is silvopasture, the integration of forestry, forage, and livestock management to provide ecological, economic, production, and social benefits. This strategy has shown the capability to facilitate agricultural producers' capacity for adapting to threats, restoring landscapes, managing natural resources and optimizing productivity for future demands.

Research has shown the theoretical management of silvopasture systems with potential opportunities towards balancing ecological sustainability and productivity. This has been focused on woodland management and forage establishment. Minimal research has shown the capacity to exhibit the integrated function and management including each silvopasture component because of reduced knowledge, financial, and land resources. This has limited the amount of information available to educate natural resource professionals, develop specific establishment and management guidelines, create and maintain long-term demonstration sites, determine proportion of economic and personnel resources necessary for application, and support financial and resource investment into practice. These gaps in research and technical guidance are hindering the reintroduction of silvopasture systems. Yet, a main gap impacting the implementation of this practice is the uncertainty of current practices and management of landowners, in addition to their knowledge of silvopasture, domestically and internationally. This warrants further exploration into the integration of this practice within international and domestic agricultural systems, thus providing an opportunity to assess current livestock practices and perceptions of silvopasture; along with potential for adaptation to stressors and capacity in restoring native ecosystems.

Dissertation Research Chapters Overview and Structure

Progressive changes in human land use and activities have led to the incompatibility of livestock and natural resource management; reducing the capacity for adapting to present-day threats. Collectively, this research aims to evaluate the capacity for integrating livestock within current natural resource management practices by adopting silvopasture or using livestock for landscape management. Integrating livestock into natural resource management practices could support agricultural producers' adaptation and resilience to current threats impeding sustainability.

Chapter 2 aims to understand the current adaptive strategies used by pastoral and agricultural communities to counteract impact of stressors in Senegal. Also, this study assessed integrating silvopasture components within the current livestock practice to aid in adaptation and resilience among commons resource management. This study can inform the development of approaches to further integrating livestock and commons resource management for increasing resilience of pastoral and agricultural communities across Senegal. Chapter 3 explores the current livestock and forest management practices among Missouri agricultural producers. This study included assessing producers' perceptions and interest in integrating silvopasture within current production operations. This study showed producers were engaging in livestock and forest management practices, with interest in silvopasture, which can be beneficial in supporting assistance provided by natural resource professionals. Chapter 4 examines using livestock for native pasture restoration by managing the invasive species *Sericea lespedeza*. This study showed that goat grazing has the capacity to impact the relative abundance of some vegetation classes and showed a potential benefit of grazing sericea lespedeza for parasitic control in goats. This study demonstrates the opportunity for integrating livestock within landscape management practices to enhance producer capacity for adaptation to invasive species, increasing biodiversity of pasture, and utilization of invasive species for forage and anti-parasitic properties.

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Chapter II: Adaptive Strategies of Pastoral and Agricultural Communities for Management of Livestock Grazing Systems in the Commons of Senegal

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Abstract

Livestock production provides economic stability and food security for pastoralist and agro-pastoralist communities in Senegal. However, stressors such as urbanization, modernized agriculture, privatization of resources, and climate change have been shown to adversely impact the resilience of communal resources. These stressors intensify the competition for resources among pastoralists (herders) and agriculturalists (farmers) within transhumance corridors. Such challenges warrant the investigation of integrated livestock strategies such as silvopasture for adaptive food production and resource management in Senegal. Between mid-October 2022 and late January 2023, a comparative case study was conducted with Programme de Développement Durable des Exploitations Pastorales au Sahel (PDEPS Sénégal) to (1) understand the adaptive strategies employed by pastoral and agricultural communities to manage stressors within the commons and (2) assess the potential of silvopasture as a strategy for land-use management of the commons. Within the pastoral zone (North) and agricultural zone (South) of eastern Senegal, four transhumance corridors were identified – each as a case – to establish regional community sampling bases. Stratified purposive sampling within communities elicited a total of 253 individuals, which represented stakeholders within the areas of pastoralism and agriculture. Semi-structured interviews and focus groups were conducted in preferred local language(s) through consented audio-recordings, translated and transcribed for qualitative analysis. Thematic analysis indicated that the majority of communities impacted by stressors reported using adaptive strategies to reduce vulnerabilities, ease pressure on commons resources, and maintain or mitigate herder-farmer relationships. These strategies were shown to vary by case region and livelihood, impacting both communal relationships and traditional agricultural systems. Findings showed a common adaptive strategy within each case region was the transition from traditional livelihood practices towards hybrid agricultural management amongst both herders and farmers, especially for communities located at the intersection between pastoral and agricultural zones. This provides

insight into the potential for agroforestry to be a viable adaptive strategy in these agricultural communities. Communities in each case region particularly expressed interest in the integration of silvopasture into agricultural activities, although approaches to disseminate this strategy must consider changes in land management associated with stressors and limited accessibility to commons resources.

Introduction

Global land use has significantly changed ecosystems, management of the landscape, and the demand for natural resources. Adaptation to these changes is essential to maintain resilience, sustainability, and food security in the face of reduced resource availability. These changes are particularly applicable on commons lands, which traditionally provide communal access to natural resources to meet societies' needs. Persistent development and natural resource exploitation threatens the resilience of commons lands in many regions, subsequently causing unsustainable management of agro-ecosystems, reduction of livelihoods, food insecurity among communities, and loss of traditional knowledge and practices such as pastoralism (Al-Bakri et al., 2013; Herrero et al., 2016).

Stress on communal land resources is prevalent within the Sahelian region of West Africa, where the dominant livestock production system is traditional small-holding transhumant pastoralism (Ayantunde et al., 2014; Blench, 2001; Fernández-Rivera, 2004). Transhumant pastoralism is characterized as a low-input, practice of seasonal, cyclic movement of livestock through various agroecological areas to secure forage and water (Ayantunde et al., 2014; Ly et al., 2010). This primarily occurs during periods of deficiency in local food and water sources. The pastoral system encompasses nomadic and semi-settled (transhumant) pastoralists, and sedentary (crop-livestock) agro-pastoralists whom support and benefit from the various functions of this livelihood including food security, economic stability, and cultural significance (Jahnke, 1982; Fernández-Rivera, 2004).

Typically, the semi-arid north Sahel grasslands meet the nutritional needs of livestock during the rainy season until the dry season, when pastoralists migrate animals towards the southern region. During the dry season, pastoralists travel within transhumance corridors – points of passage to access dispersed resources – with livestock for grazing of high-quality forage and crop residues to secure herd survival and production (Diop et al., 2014; Kitchell et al., 2014). This mobility reduces pastoral communities' vulnerability to climatic change and ensures sustainability. Over time, cooperative livestock-agriculture relationships have developed between pastoralists (herders) and agriculturalists (farmers) (Ly et al., 2010), which facilitate herders' travel within these corridors for sustainable production and management of livestock (Diop et al., 2014; Kitchel et al., 2014).

However, various external factors such as urbanization, modernized agriculture, and climate change have threatened livestock management and this cooperative relationship (Herrero et al., 2015). This is due to the intensification of land use, which has impaired both agricultural productivity and ecosystem services, and, ultimately, adversely impacting the resilience of communal resource management (Blench & Marriage, 1999; Ellis & Galven, 1994; Freudenberger & Freudenberger, 1993; Mortimore & Turner, 2005; Moyo et al., 2007). For instance, small-scale farmers and herders that rely on arable land resources and livestock mobility are particularly affected by erratic rainfall patterns and poor soil quality induced by climate change and land degradation (Martin et al., 2016). Consequently, this increase in marginalized land leads to decreased agricultural productivity and low availability of forage for livestock. Additionally, constant pressure has grown for modernization, transitioning from subsistence farming to commercial agriculture. This rapid expansion of commercial agricultural land further destabilizes local markets and depletes commons resources (Rohde et al., 2006; Steinfeld et al., 2006). Stress on available resources fuels negative tensions within the relationship between herders and farmers (Brottem, 2016; Freudenberger & Freudenberger, 1993).

Given these significant changes in agricultural systems, livelihoods dependent on transhumant pastoralism in Senegal have become threatened (Fernández-Rivera, 2004; Houessou et al., 2020; Jahnke, 1982; Steinfeld et al., 2006). Adaptive approaches are warranted to ensure the protection of commons resources and resilience of pastoral and agricultural communities in response to continuous stressors. Silvopasture, an agroforestry practice of incorporating woody perennials and forage within livestock grazing systems, has the potential to be an adaptive strategy for resilience. This practice can supply adequate, diverse forage and fodder, and alleviate tensions among herders and farmers (Jose & Dollinger, 2019). Furthermore, silvopasture provides numerous benefits to improve animal health and productivity, diversify economic markets, improve forest management, and support pollinator and wildlife habitats (Klopfenstein et al., 1997).

The pastoral grazing system consists of grazing between grasslands and browsing in woodlands, thereby facilitating adaptation towards silvopasture systems. Silvopasture could facilitate the growth of native pasture shrubs and grasses in the northern pastoral region and maximize growth of nutritious forage in the understory of the tree canopy landscape transitioning to the southern agricultural region. Among agro-pastoralists and farmers, specifically, there is potential for a diversified income of value-added woodland products and improved soil quality with land management for higher crop productivity. Development of adaptive strategies such as silvopasture for sustainable land management and grazing practices is key to potentially reducing vulnerabilities, easing pressure on commons resources, mitigating herder-farmer relationships, increasing resilience and adaptation, and provisioning of beneficial resources and ecosystem services.

A comparative case study will facilitate an in-depth understanding of the adaptive strategies adopted by communities to manage stressors within the commons and assess the potential of silvopasture as an alternative strategy for sustainable community-oriented land-use management of the commons. This qualitative approach using targeted semi-structured interviews was used to meet the study objectives: (1) identifying the adaptive strategies employed by pastoral and agricultural communities to manage stressors within the commons, and (2) assessing the potential of silvopasture as a strategy for community-oriented land-use management of the commons. To address the first objective, two study questions were posed: (1) *What adaptive strategies have participants adopted to mitigate the stressors on communal resources* and (2) *What are the participants' views surrounding tensions between pastoralists and farmers?* To address the second objective, the study question posed was: *What are the participant's perceptions of silvopasture components and its utility within Senegal?*

Materials and Methods

Research Credibility and Connection

As an Agroforestry Extension Specialist in Peace Corps, the primary researcher observed the conflict among pastoralists and agriculturalists in the availability of commons resources. To facilitate this project, the researcher expanded on previous language study to enhance language proficiency in Mandinka and Wolof, and cultural fluency for conducting data methods of semi-structured interviews and focus groups.

Case Study – Study Area

Senegal (Figure 2.1) is situated in West Africa within the Sub-Saharan-Sahelian zone. Senegal's topography is characterized by diverse bioclimatic regions that determine the vegetation type and livelihood corresponding to the regional climate conditions. Northern Senegal (sylvo-pastoral zone) consists of the semi-arid Sahel, a warm desert climate, which host herding communities. Senegal's central (transitional zone) and southern (agricultural zone) regions are comprised of the warm semi-arid Sudanian region, which includes a mixture of vegetation and wooded savannas for farmers, agro-pastoralists, and forest-dependent communities. Senegal's southernmost region contains the tropical savanna sub-Guinean region that supports rice production and flora and fauna conservation (i.e., Niokolo-Koba National Park) among dense forests, mangrove estuaries, and marshes. Throughout these bioclimatic regions are four major rivers – the Senegal, Saloum, Gambia, and Casamance, which support livelihoods and diversity among flora and fauna. These bioclimate regions undergo three primary seasons 1) cool, dry winter season [November – February], 2) hot, dry season [March – June], 3) hot, humid rainy season [July – October] with variations in regions. These climates and regions support an economy based on agriculture that represents the main economic activity within the country, accounting for 17% of the gross domestic product (GDP) and employing 70% of the population (CIAT, 2016). Over time these sectors have continued to be negatively affected by drought, rapid population growth, unsustainable resource management (e.g., overharvest of trees, overgrazing, overfishing), and intensification of agriculture, which has resulted in enormous stress on limited land resources.

Comparative Case Study Research Design

A case-comparative qualitative approach was used to facilitate the in-depth assessment of the common resource management phenomenon in eastern Senegal (Crowe et al., 2011; Bartlett & Vavrus, 2017). This approach enabled valuable community perspectives to be secured, supporting the understanding of the stressors impacting farming and herding stakeholders, and the various adaptive strategies utilized among these groups. Cases, the unit of analysis, were defined and identified in partnership with Programme de Développment Durable des Exploitations Pastorales au Sahel (Program for the Sustainable Development of Pastoralists in the Sahel, PDEPS Sénégal). Four total cases were established across the pastoral (North), transition (Central), and agricultural zones (South) of eastern Senegal, delineated by ecological zones amongst five transhumance corridors: Podor – Gambian border, Linguere – North Kaffrine, Tambacounda-Bakel, Kolda, and Kedougou, used as reference points to ensure geographical representation (Figure 2.1).

Within each case, regional bases were identified as major intersections of stakeholder representation (Figure 2.1). Also, regional bases served as central points for the accessibility of participants within the surrounding communities and aiding in sampling methods and data collection within natural settings. Among the regional bases, villages (n = 6) were indicated within close (n = 3) or distant (n = 3) proximities to central points to establish within-case parameters. These cases were identified through guidance of PDEPS and fixed upon agreement of community to target a multitude of stakeholders along the Northeastern and Southeastern regions.

Case Study Sampling and Methods of Data Collection

Stratified purposive sampling was used to elicit a reasonable representation among individuals sharing characteristics of agriculture and farming livelihoods within the population (Neyman, 1934; Suri, 2011; Robinson, 2014). Sampling groups were determined through demographic profile of the estimated population of stakeholders throughout each region. To minimize research selection bias, the PDEPS facilitator connected with the village chief or point of contact to identify key individuals within the following groups: herder, farmer, women, elder, and leader (i.e., religious or organization). Various stakeholders within these groups were included along with women landowners and farmers to provide diverse and balanced inputs.

Throughout the harvest dry season, which lasted mid-October 2022 until late-February 2023 in each ecological zone, the field research team – project coordinator, PDEPS facilitator, and research assistant conducted semi-structured interviews and focus groups, referencing the co-production of knowledge methodological process to enhance the integration of local and external knowledge (Armitage et al., 2011; Boillat & Bottazzi, 2020). Semi-structured interviews and focus groups provided an appropriate format for discussing sensitive topics and ensuring natural flow for expression of participants' ideas and beliefs (Adams, 2015). Semi-structured interview guidelines were used to elicit responses among pastoralists, agro-pastoralists, farmers, and foresters to facilitate articulation of traditional knowledge of agroecological systems (Fylan, 2005). Interview discussion questions were developed in collaboration with PDEPS to engage individuals involved in the low input agroecological grazing systems and reviewed by researchers and collaborators for clarity and comprehensiveness. Focus group discussions included participatory observations to promote strategic thinking of the stressors and adaptive strategies in the commons. Data collection continued until the point of saturation. At such point, interview questions were modified to capture additional information. Additionally, in-field observations were completed with field notebook to gain further understanding of common resources and participant knowledge (Mulhall, 2003). Document analysis was conducted additionally to support capturing the underlying unstructured elements and encapsulate traditional and local knowledge and experience among communities (Morgan, 2022).

To maintain trust and relationships, data collection was intertwined within Senegalese local infrastructure, culture, and customs for a total of eleven days (Figure 2.2). Such actions encouraged immersion within the case regions to connect with the local communities, facilitate observations, and promote a natural setting to ease discussion of sensitive cultural and livelihood topics (Korstjens & Moser, 2018; Dado et al., 2023). Semi-structured interviews involved a maximum of five individuals, with an additional five to seven individuals included in the focus groups. Because Senegalese culture values community involvement, flexibility was granted for additional participants within focus groups to be included in observations. During interviews and focus groups, verbal consent for involvement was provided by participants to ensure adherence to University of Missouri Institutional Review Board (IRB) standards (Project# 2090473). In the event a participant denied consent for audio recording but wanted to participate within the project, responses were recorded through written form. Personal information of participants' name, age, village of residence, and livelihood were documented prior to recording and stored securely with the project coordinator to ensure privacy.

Local PDEPS facilitators within each region served as interviewers, conducting the interviews based on the participants' language preference (i.e., Wolof, Pulaar, Mande, Serer, or Jolof) to minimize language barriers, optimize the interpretation of responses, and secure authentic relationships. The project coordinator facilitated the progression of the interviews by guiding discussion and probing additional questions for exploration of discussion topics. Furthermore, the project coordinator noted observations during the interview process. Interviews and focus group discussions were recorded using the voice memo function on an approved research project cellular device for optimal voice quality (Houghton et al., 2013; Morse, 2015).

Data collection continued throughout villages for a total of eight days, with a day reserved in between for rest, followed by travel day to return to capital city (Figure 2.2). Upon the conclusion of the field visits, field observations were expanded during reflection to memos, and a debrief meeting was held with in-country and University of Missouri project advisors. Moreover, audio recordings were delivered anonymously to vetted personnel with skill in multiple language proficiency for simultaneous translation and transcription. Secondary translators reviewed transcripts for accuracy and validation. Transcripts were then further reviewed to familiarize coder, cleaned, and prepared to import coding in Nvivo 14 (2023, Denver, CO) software for template analysis.

Coding, Thematic Analysis, and Validation

A codebook was developed to reference and facilitate the coding of transcripts, observation memos and documents (Table 2.1) for thematic analysis. Thematic analysis was used to search across the data set to uncover themes and inform within-case and cross-case interpretations (Guest et al., 2012). Initial codes were used to facilitate a deductive coding approach in line-by-line coding to indicate patterns within transcripts and memos. Identified codes were labeled and synthesized to create categories. Categories were collapsed or expanded by characterizing conceptual similarities and relationships to uncover emerging themes. Subsequently, theme reports were submitted to project collaborators for peer debriefing to reduce bias, promote feedback and maintain a sense of objectivity in perspective and limitations for conceptual development (Morse, 2015).

Concepts and perspectives associated with themes were interpreted by using resilience and adaptive strategy frameworks. These frameworks provide structured approaches for building the capacity of individuals or communities to mitigate and recover from stressors. Also, these frameworks assist in establishing strategies to reduce vulnerabilities and increase security within systems (Birhanu, 2017; Boillat & Bottazzi, 2020). Additional frameworks were utilized to provide credibility explanations to findings including the Drivers-Pressures-State-Impacts-Responses framework (DPSIR). The DPSIR framework is used to assess and manage environmental problems associated with socio-economic and socio-cultural forces driving human activities to influence or mitigate pressures on the environment (Kristensen, 2004).

Findings were validated through peer debriefing by gathering with the Ministry of Livestock and Animal Production in Senegal. Further validation included member checking, the approach of presenting the emerging findings or final analysis to the research participants. This aimed to increase validity of the case study and to maintain repour with the community (Lincoln & Guba, 1985; Morse, 2015; Candela, 2019). Case study participants were invited to a validation discussion during regional meetings hosted within the cases. Discussions included a verbal delivery as form of information transfer to ensure participant viewpoints and responses were accurately captured.

Results

Majority of communities among the cases engaged in herding or farming activities, which support agricultural livelihoods within the common lands of the north and south-eastern regions of Senegal. This study confirmed herding activities persisted amongst communities subsiding within the northern Sahelian region, known as the sylvo-pastoral zone designated primarily for herding activities with some farming activities during the rainy season. Farming activities mainly occurred in the transition zone, which marks the boundary between the arid and humid ecological zones. This area is characterized by more farming activities with infrequent permanent herding activity. Farming activities became more prevalent and integrated with livestock and forestry practices within the Casamance zone, as the landscape changed between semi-arid to central sub-humid into the humid savannas.

Herding and farming activities throughout these agro-ecological zones were shown to support livelihoods ecologically, economically, and socially. Pastoralism showed to be interconnected between herders and farmers, especially along transhumance corridors. As communities within proximity to the corridors expressed the importance of pastoralism to Senegal and agricultural communities. An interviewee states: *"it's important for the country because we feed people and farmers also come to look for manure for empowering their farms because it's very useful and more healthy. "*

Yet, most communities acknowledged this practice known historically to sustain resource management resilience tended to be particularly vulnerable to stressors. Moreover, pastoralism was found to induce resource competition causing more strain between herder-herder and herder-farmer relationships. This case study revealed three themes corresponding to changing herding and farming livelihoods, internal and external stressors, and adaptive strategies employed among communities to reduce vulnerabilities, reduce pressure on and competition of commons resources, and mend herder-herder and herder-farmer relationships.

Theme #1 – Changing of Herding and Farming Practices and Livelihoods in the Commons

Among each case region there was a common perception that pastoralism was beneficial, such as by providing manure, clearing crop residue, and supporting economic growth. This practice proved to be valuable to herding and farming communities. Though stressors impacting pastoralism have inevitably changed herding and farming activities within Senegal. Consistently, communities explained how this changing of herding and farming activities has resulted in increased competition among herders and farmers in using commons land resources.

Most communities within each case region noted changes in these livelihoods, and subsequent competition that has amplified with the development of Senegal. This development is substantially impacting herding and farming practices. This has specifically occurred with the monetization of agricultural products and cultural behavior change around these livelihood activities. Progressive development of the country has resulted in technological advancements, escalation of urbanization, and exponential population growth. Farmer interviewee: *"... the population is increasing, where one person used to farm now three people farm there and villages become bigger; people create new cities and houses, but we have to leave space for animals and farming also."*

Collectively, case communities debated the benefits of such developments as modernizing agriculture, increasing access to transportation, availability of electricity, and the growing ease of currency transfer provided more accessibility to products and opened opportunities to markets. These developments also increased the monetary value for products and increased access to services such as healthcare, education, and community growth. These benefits were strongly appreciated by within-case communities in closer proximity to markets compared to further situated communities, that had transitioned away from herding and farming activities. Though communities fully engaged within herding and farming comprehended these benefits, these developments also caused a reduction in land space and tended to cause strain on resources once readily available for agricultural activities. This was most apparent among farming communities within the transition zone and communities engaged in transhumant herding, traveling from the sylvo-pastoral zone. An interviewee articulates the trade-offs within herding:

> *…we lose something, and we win another thing depending on the past and today. In the past, for instance, it was very easy to find resources of food for cows and to find water. Everywhere you went, you didn't need to walk long distances to find food because it was available, but now it is difficult to find food. You walk long distances and sometimes at some point of the year you are out of food everywhere, but also now people make more money from cows and milk. What we don't have now, we had in the past, which was resources; and what we have now, and did not exist in the past is profit from herding.*

Recognition of the impact of development on agriculture was not only expressed by herders, but also by farmers, especially within the southern case region. A farmer (male) described:

> *In the past people would work in a place for just a few years and let the soil rest. Now, the only solution is to spread fertilizer on the field. We have always been diversifying our field crops. We never grow only one type of crop. But it is hard to diversify crops because there are more farmers now and the land has not grown in space. The villages are growing as well as the population. People don't have the option to have multiple fields because you cannot keep cutting the bush (forests) – the government would not allow you to.*

Beyond the change in land and resource availability, development has led to an expansion in productivity among agricultural livelihoods to compete with the demand of a growing population and economic growth.

Theme #2 – Impact of External and Internal Pressures on Natural Resource Availability in the Commons

Throughout the cases, communities within each case region discussed a range of persistent stressors including urbanization, modernized agriculture, climate change, and landscape degradation, which has threatened livestock management and increased competition between herders and farmers. For instance, usually, the north Sahelian grasslands provide the nutritional needs of livestock during the rainy season, until the dry season prompts herders to move animals toward the southern agricultural zone. However, due to environmental and human-induced threats changing food and water resources, northern herders are changing traditional migration strategies.

Mutually, herding and farming communities in each case region were shown to be most vulnerable to climate change adversely affecting rainfall and land productivity. Though progressive changes have been witnessed throughout time, present conditions varied across case regions, described as cautious, severe, and detrimental to future activities. These changes include irregularity during the rainy season and a drastic decline in rainfall. This has caused a lack of water supply insufficient to meet the needs of northern herders and central region farmers until the following season: *"The problem we are facing is the lack of water. The rain is very irregular and that is not good for the crop."* (Farmer, Male)

Water scarcity has also resulted in land desertification, which has progressed since being noticed in the late 1950s. Northern herding communities residing in the Sahel seemed to be more impacted by desertification, noticing a significant change in soil and vegetation, reduction in trees, limiting access to resources, and increase in human and animal population. This change was described by a herder (male) who stated:

> *It changed a lot, in the past we had so much space, food and access to water. There were not a lot of diseases at that time also and when losing an animal we will find it easily but now we have lack of space, lack of feed, lack of water and a lot of diseases because people and animals increase.*

Beyond the increase in human and animal populations, herding and farming communities within each case region suggested the clearing of trees to significantly impact rainfall, desertification and soil fertility. An interviewee expressed: *"Changing lands every year is having an impact on the environment as they have to cut trees all the time. The more they change farms, the more trees we lose."* (Herder, Male)

Farming communities within the central region tended to accept expansion of farms were attributing to the loss of forest, though claims were also made that northern transhumant herders were the cause because of cut and carry practices. This tended to be a topic of opposition between herders and farmers within the northern (sylvo-pastoral zone) and central (transition zone) regions. Other activities mentioned to be causing deforestation were gold mining and logging by international enterprises and charcoal production, which were growing in the southern (Casamance zone), and development nationally.

Such climatic and population changes were shown to have increasing pressure on herding travel patterns and distances, causing interference with harvesting season. This was most prominent with farming communities in the transition zone because of proximity to the sylvo-pastoral zone, and thus the principal area for migration. Some herding and agricultural communities also mentioned herding activities encroaching on regions with additional land management priorities such as forestry and wildlife conservation for necessity. This occurrence was mainly discussed among villages adjacent to, or within proximity to country-country borders as indicated by an agro-pastoralists (male):

> *We are not far from the Gambian border and Gambian herders liberate their animals earlier… the Gambians spend the whole rainy season here until the dry seasons because there, they farm all the land, and there is no space to feed the animals. That has brought a lot of conflicts and there is no border control system to stop them from crossing.*

Farming communities within these southern areas mentioned difficulty in managing relationships with transhumant pastoralists because of persistent damage to crop production. However, Senegalese herders explained that there is a lack of resources and additional farms created in recently traveled paths have shifted the landscape of herding. This is due to a reduction in commons land resources being converted into private production for intensive peanut cultivation by local and international companies, restricting access to water sources for damming or irrigation practices, and central region farmers enclosing cultivated fields to restrict animals access to grain and vegetable crops. These factors, in addition to droughts, have increased the pressure on the landscape and further heighten the competition for resource availability between herders and farmers.

However, in the southern case regions, these stressors have not had as significant of an impact on resource competition between herders and farmers, as a farmer (male) explained the possibility of cooperation between the groups:

> *… because the land is for everyone. Depending on the moment each part can have what he needs without causing any damage to the other part and herders can stay more than three months in one place; they move and we can take back our field. What they need is to feed their animals and what we need is to empower our farms. We should be able to*

negotiate to avoid fights because there are a lot of conflicts between herders and farmers and sometimes people die during these conflicts.

Most communities among each case region discussed or alluded to the need for the integration of trees and animals for resource availability within the commons. These resources include integrating trees and fodder sources: *"It will help a lot to have trees that produce food for animals and animals that produce manure for the farmer"* (Farmer, Male).

However, opposition was expressed among a few north and central case communities towards certain aspects of this integration because of apprehension on the lack of knowledge, potential loss of space, and individual ideologies.

Theme #3 – Internal and External Adaptive Strategies to Mitigate Pressures and Conflicts

To adapt to internal and external stressors and maintain or mitigate relationships between herders and farmers throughout the regions, communities discussed engagement in various strategies, specific to the needs of the livelihoods (Table 2.2). Increasingly common strategies among younger individuals throughout each case region were seeking employment with gold mining companies, migrating to urban areas, and immigrating to bordering and international countries for economic opportunities. A common strategy presented among each case region was the movement of animals within designated transhumance corridors to access forage and water resources. This has been particularly reported as a major coping strategy among northern herders throughout the Sahel region. However, due to erratic changes in rainy season and rainfall further reducing forage and water resources, herders have begun departing earlier, traveling further into southern regions of Senegal to locate resources for livestock. These shifts in timing and space of movement have influenced the presence of livestock in closer proximity to cultivating areas, especially in the transition zone. An interviewee explains: *"Previously we were away from the* *farmers so as not to disturb them in their field but now we are going in search of pasture even if there are no fields; we are looking for food for our herds."* (Pastoralists, Male)

Because this strategy has further compromised relationships among agricultural actors, organizations and governmental entities have intervened to map and install permanent corridors. These corridors were found to secure pathways for herders' movement of animals and protect farms from animals passing, as a farmer (male) described:

> *It's important for farmers and herders also because it helps animals to move easily without going into farms; if they respect it (herders and farmers), it can save farms, which means no farming in the corridor and where animals go to drink.*

Herders mentioned especially utilizing corridors in addition to local connectors pathways in accessing forest classes, sectioned spaces of forest meant to act as reserves for grazing within times of scarcity. Thus, the delineation and protection of transhumance corridors are critical to maintaining livestock mobility by allowing passage through areas of increasing cropping pressure. Even case region communities without an established corridor acknowledged the existence of this strategy, and the function and benefits to reduce conflict and prevent agricultural encroachment on commons animal passage. Mainly northern herders discussed developing pastoral units and organizations to locally regulate grazing activities, represent pastoral interests, protecting rights to resources, and livelihood of the pastoralists.

Supplemental strategies were described to secure food for animals. These entailed herders gathering grass during the rainy season to store for periods of shortage or cutting tree branches to carry to animals. Herders also mentioned storing or buying crop residue to feed animals towards the end of the lush season. Increasing prevalence was the strategy of purchasing *aliment*, livestock feed, for animals such as buying cotton grains to increase cow's milk production. Though complaints were consistent among herding communities on the expensive costs, regulation, and availability of livestock feed, many herders mentioned participation in this strategy due to reducing forage availability. Since uncertainty has persisted around herding activities a few herders within northern regions have chosen to transition from herding activities to specialize in solely agricultural business enterprises (e.g. shop owners, sellers, livestock middlemen).

Central region farming communities adjacent to the silvopastoral zone seemed to be greatly impacted by stressors and shocks affecting pastoral communities. To adjust, farmers spoke about fixing borders around farms to deter passing grazing animals (Table 2.2). This was especially common with farmers further from established corridors and those who started managing their own animals and desired to store crop residues for personal animal feed sources. Moreover, in maintaining or increasing crop production against environmental factors, farmers primarily used chemical fertilizers to enrich soil fertility, though admittedly recognized the harmful effects to the soil and land. As inconsistent rainfall continues to threaten farming activities, farmers discussed continued use of fertilizers out of necessity to ensure food for families and if possible, produce additional products for income. Further strategies implemented to secure income were renting land to urban populations demanding land for agricultural activities, and expansion of home gardens, mainly operated by women.

Southern regional herding and farming communities were less vulnerable to stress but also discussed employing current strategies to protect and conserve resources. These strategies were geared towards the protection of the forest, further managing mixed agricultural activities, and integrating agroforestry techniques to improve resource management and diversify economic activities (Table 2.2). These communities tended to consist of groups engaged in traditional farming practices, near protected forests, or having traditional knowledge of balancing livestock and farming practices. A southern farmer (male) articulates this by stating:

We take care of our forest. We don't want people to cut big trees or to cut all the trees. We control it and we are very serious about it here because our lives depend on it. We also plant trees now because we are more aware of the importance trees.

Additionally, these communities mentioned strategies such as creating firebreaks, discouraging charcoal production, and accepting the training and assistance from Eaux Foret, the Senegal Forest Department, and Peace Corps (Table 2.2).

Discussion

Pastoralism, as a traditional livestock system, is known to be an essential component of agricultural livelihoods providing economic opportunities, securing food security, and maintaining balance within management of commons landscapes. This was acknowledged among both herding and farming communities within our study case regions that acknowledged the importance of pastoralism and the benefits this practice provides. This perception consists of benefits from pastoralism noted in other studies globally including ecological services, economic contribution and food production (Abduletif, 2019). Pastoralism in Ethiopia was indicated as significantly contributing to the country's gross domestic product (GPD) and providing economic and food security to individuals involved and benefiting from pastoral activities (Abduletif, 2019). Researchers have also characterized this traditional practice as ecological, facilitating the sustainable production of livestock and management of diverse ecosystems within communal areas (Wezel et al., 2020).

Over time, pastoralism as a management strategy has been impacted by growing stressors contributing to increased competition among agricultural stakeholders. Studies in West Africa have reported heighted conflict among agricultural stakeholders because of changes in land and resource availability, specifically population and economic growth (Gefu & Kolawole, 2002; Fasona & Omojola, 2005; Adisa, 2012; Babagana et al., 2019;). Gefu & Kolawole (2002) conducted a study to estimate the potential impact of converting dry season grazing areas into irrigation farming. This originated from a proposed project in Nigeria to utilize flood plains and wetlands for irrigated agricultural production among local producers. Gefu & Kolawole (2002) reported that herder-farmer conflict pre-existed the project because of farm encroachment of mobility routes and watering points enticing crop damage. Also, the authors noted that conflict grows during herder and animal migratory return to northern region during the beginning of rainy season. It was suggested that development of flood plain and wetlands to exclusively crop irrigation farming would severely disadvantage herders and increase recurring conflicts. Our study showed similar instances of land use change for intensified agricultural production that has limited or restricted herder accessibility of commons lands. This was shown to greatly impact northern herders timing of travel and routes, further contributing to increased competition within and outside of the sylvo-pastoral zone.

Similar conflicts were discussed in the north-central region of Nigeria, in addition to the change in resource access rights and increasing crop cultivation to meet the growing population (Adisa, 2012). These transformations in herding and farming activities, coupled with constrained resources and expanding climate change, were shown to enhance the pressure of intensified agricultural production that leads to the depletion of soil quality, increased deforestation, reduced rainfall with shift in timing, desertification, and landscape degradation (Fasona & Omojola, 2005). Freudenberger & Freudenberger (1993) also assessed such impacts to include the expansion of sedentary agriculture and land conversion. This report explains how the increase in agricultural irrigation led to sectioning off and salinization of major water sources, thus prohibiting animal access to drinking water provided by the Senegal River. Such instances were also reported in other countries in West Africa, in which intensification of agriculture resource availability impacted local agricultural livelihoods (Gefu & Kolawole, 2002; Adisa, 2012). Moreover, Freudenberger & Freudenberger (1993) particularly noted the intensification of

Senegal's peanut production that induced further exploitation of soil and commons resources, in which fertile grasslands have become unsuitable for cultivation and useless for grazing practices. Grazing practices have become further threatened by conversion of commons lands for urban settlements and privatization of commons spaces to support growth of farming (Freudenberger & Freudenberger, 1993; Gefu & Kolawole, 2002). Now, twenty-nine years later, these stressors continue to impact herders access to commons resources, with the most impacted communities in our study being northern herders and subsequently herders and farmers within the agricultural transition zone. This warrants further research into policies to protect commons resources and strategies to adapt and manage these remaining commons land resources.

Water scarcity has also resulted in land desertification, which has progressed since being recognized in the 1950s. Desertification has been shown to spread further throughout sub-Saharan Africa including Senegal, exacerbated by the clearing of trees, exploitation of resources, and increase in human and animal population (Hein & de Ridder, 2006). Progressive reduction in rainfall has also been reported in the Guinea-Sudan-Sahel zones in Nigeria with similar impacts on commons resources (Fasona & Omojola, 2005). This decrease in rainfall has negatively changed the land cover in the area, impacting agricultural stakeholders by stressing access to resources. Such changes in precipitation have been observed by pastoralists within western and eastern Africa (Kihila, 2017; Napogbong et al., 2020; Tugjamba et al., 2023). This has affected herders' access to resources, impacted timing of pastoral activities and quality of grazing lands (Napogbong et al., 2020; Tugjamba et al., 2023). To resolve the water shortage, practitioners have begun digging more wells or extending the depth to tap into ground reserves. In Senegal, Freudenberger & Freudenberger (1993) discusses the creation of boreholes, narrow, deep holes for extracting groundwater that became common practice for herders gaining access to water for animals. Though this restricted movement capability and caused reliance on these water points. Each community within the case regions of our study described the change in rainfall impacting both agricultural and herding communities. Northern herding communities discussed water point sources installed to assist with water access, but also spoke to the continued challenges of access, management, and associated costs. Central herding and farming communities also discussed the increased competition because of the lack of water, and deciding which stakeholder group caused the issue, and using strategies to alleviate this resource stress.

Adaptive strategy is the method used by an individual or community to manage the impacts of stressors to influence system resilience to reduce long term vulnerability and improve security and livelihood (Armitage et al., 2011). Each herding and farming community in our study described employing current adaptive strategies towards decreasing competition, managing resources, and building resilience. Most northern herding communities noted the use of permanent transhumant corridors as a primary strategy in adapting to growing stressors. This strategy was shown to be favorable because it established pathways mainly for herders and eased travel for accessing forage and water. Herding and farming communities in other regions, particularly central region farmers also validated this strategy as it reduced incidences of livestock entering farms, especially during the harvest season. This has also been reported as a major coping strategy among pastoralists throughout the Sahel (Freudenberger & Freudenberger, 1993; Ayantunde et al., 2014; Birhan et al., 2017; Napogbong et al., 2020). Kitchell (2014) reported similar functions of corridors in the eastern Senegal region within proximity to the Senegal river and Mauritania - Mali borders. This study involved meetings with local districts to assess perceptions towards mapped corridors, finding recognition of established corridors and consensus about functions. Though corridors provided services for mitigating conflicts and accessibility of resources, issues were raised towards the governance of these corridors, customary rights and responsibilities warranting further discussion, management policies, and formations of local groups to advocate for pastoral rights (Kitchell et al., 2014).

Since uncertainty has persisted around the resiliency of herding activities in Senegal, a few northern herding communities within our study mentioned transiting from herding activities to specialize in solely agricultural business enterprises (e.g. shop owners, sellers, livestock middlemen) (Adisa, 2012; Kihila, 2017). Manoli (2014) also reported such strategies along with the modification and dispersal of families into small groupings to balance workforce and consumption needs. In our study, other herders discussed migrating and settling in regions surrounding the sylvo-pastoral zone, foregoing the transhumant activities, and becoming agro-pastoralists, mixing herding and farming, or only engaging in farming activities (Freudenberger & Freudenberger, 1993; Blench, 2001; Fernández-Rivera, 2004; Kihila, 2017).

To adjust to the changing climate and landscape, farming communities in the central region of our study spoke about fixing borders around farms to deter passing grazing animals (Gerfu & Kolawole, 2002; Mertz et al., 2009; Adisa, 2012). This was especially common with farmers further from established corridors and those who started managing their own animals and desired to store crop residues for personal animal feed sources (Mertz et al., 2009). Freudenberger & Freudenberger (1993) also describes this change of farmers transitioning from dependence on monoculture crops (i.e., peanuts) to begin cultivating a wide variety of nice products including watermelon, pumpkin, hibiscus, and cereals. Herding and farming communities within the southern region of our study noted being less impacted by stressors, though mentioned using strategies such as integrating tree and livestock practices to build resiliency to these approaching threats.

Studies have shown benefits of incorporating fodder trees in livestock grazing systems, which contributed to improved livelihoods of livestock communities by diversifying feed sources, enhancing animal performance, and provisioning additional ecosystem services (Niang et al., 1996; Franzel et al., 2014; Debeux et al., 2017). Moreover, the integration of tree components within tropical herding and farming activities have shown the capability in providing socioeconomic and production benefits and facilitating improved husbandry and resource management practices for climate adaptation and mitigation (Molua, 2005; Mbow et al., 2014a; Mbow et al., 2014b). Research has shown the necessity for enhancing the development of adaptive coping strategies such as silvopasture to build resilience to environmental and human stressors impacting herding and farming communities (Mbow et al., 2014a; Birhanu et al., 2017) Birhanu (2017) explored this among Ethiopian pastoral communities impacted by recurring drought, which reported engagement within combination of adaptive agricultural practices and alternative livelihood opportunities that could strengthen community resilience systems. This consensus was reported among Kenyan pastoralists participating in activities to include bee keeping, grazing management, afforestation, establishing fodder trees, and cultivating fruit trees, contributing to resilience (Muricho et al., 2019).

Beyond these strategies silvopasture has the potential to facilitate sustainable resource management, mitigating climate impacts and stressors, and building resilience within herding and farming livelihoods. Amongst communities within our study case regions, recognition of the terms *silvopasture* or *silvo-pastoralism* remained low. A few individuals indicated an awareness of silvopasture from meetings with international organizations that had presented information on agroforestry practices. Some individuals, within the southern humid regions explained having traditional knowledge of silvopasture components and engaging in such practice. Both herding and farming communities presented favorable perceptions towards silvopasture and expressed interest in considering silvopasture as a potential adaptive livestock practice for sustaining livelihoods, managing commons resources, and ensuring resilience to environmental and human-induced stressors. Participants also described benefits from the practice that could feasibly provide for herding and farming communities. These primarily included diversifying forage for animals (e.g., fodder trees, crop residue), securing food for human consumption, producing manure in fields and enriching soil fertility, increasing crop production, expanding economic opportunities, and reducing herder-farmer resource conflicts.

Agro-pastoralists and farmers in southern regions expressed interest and willingness to integrate silvopasture by planting trees for afforestation, restoration, or expanding current forest management practices. This is due to the prevalence of local knowledge and access to resources, though mentioned demand for training on enhanced management practices and conserving and regenerating local tree varieties. Farmers within the central transition zone of Senegal also expressed interest in planting trees, though voiced concerns regarding the absence of fences to protect young trees from animals. Furthermore, communities discussed limited protection methods to safeguard trees against bushfires. Herders within the northern region seemed the most interested in planting trees to provide supplemental forage for animals and alternative income sources. Unfortunately, these communities were the most vulnerable to climate change and lacked consistent water sources for tree establishment and maintenance. Strategies were posed for herders to aid farmers with tree planting in exchange for seasonal access. Though communities expressed interest in the practice, challenges were mentioned that could hinder adoption and utilization of this strategy. Challenges included inconsistent access to resources (i.e., water, land and tree ownership), gaps in practice knowledge and understanding, limited training opportunities, and persistent competition between herders and farmers. Additional challenges were issues of land tenure and tree ownership, as well as changes in social dynamics, which incited hesitation of such strategy.

Conclusion

Most of the interviewees within the case study engaged in herding or farming activities, which aligns with Senegal's agricultural characteristics. Agricultural livelihoods have progressively been impacted by shocks threatening community resilience, negatively affecting the environment, reducing commons resource availability, hindering the local economy, and changing cultural and social behavior. This was mostly attributed to climate change, population growth, and modernized agriculture.

Majority of the communities within the case regions were impacted by these stressors, which have impacted resource availability and subsequent relationships between herders and farmers. Northern case regions appeared to have experienced significant challenges of reduced food and water resources for livestock from these stressors resulting in changes in herding and agricultural practices. Communities within this region also alluded to challenges of agricultural and urban encroachment into common grazing lands, further limiting access to forage and increasing water stress. Case regions situated within the transition between the northern and southern regions commonly mentioned the intensifying pressure on farming fields with reduced rest periods and burden to clear trees for more farming land. Southern case regions also seemed to experience such challenges at a reduced scale, though anticipate progressive challenges in water scarcity with decreased rainfall and dependence on chemical inputs for food production because of diminished soil quality.

Herding communities within the silvopastoral zone were found to engage in strategies to sustain the commons and minimize herding-farming conflict, such as modifying temporal and spatial movement patterns and using permanent transhumant corridors as secure pathways for livestock mobility. Herding communities also indicated migrating and settling in surrounding arable regions to further integrate more sedentary farming activities for economic stability. Farming communities within proximity to the silvopastoral zone demonstrated strategies that restricted accessibility of communal resources, including creating borders around arable land to deter grazing of passing livestock and retaining harvestable livestock feed. Moreover, farming communities surrounding the silvopastoral zone began managing and integrating livestock within individualized farming operations.

Among these primary strategies, the use of transhumance corridors seemed to be the most effective currently facilitating herder movements and reducing human-conflict. However, as persistent land degradation and consequent reduction in forage availability force herders further south within the country, the competition between herders and farmers for access to resources, especially along transhumance corridors is expected to grow. Thus, the development of sustainable resource management and grazing practices, such as silvopasture is key to potential adaptation and resilience to shocks hindering availability of commons resources and impeding collaborative management between herder and farmer communities within the commons.

Silvopasture remained favorable among herding and farming communities, as participants explored the ecological, economic, and social benefits. This mainly was centered around the system possibly reinforcing land resources, providing fodder sources for animals, and diversifying economic opportunities, among provisioning other ecosystem services. Though it was apparent to participants that gaps in knowledge, access to resources, and local customs surrounding trees and land ownership were limiting factors for practice implementation. This warrants the necessity for local investment and support into building herder and farmer capacity for the application of silvopasture. Mainly due to the presence of traditional management practices that could facilitate transferable knowledge, international and local partners promoting alternative agricultural activities including agroforestry and expressed interest among herders and farmers throughout the case regions.

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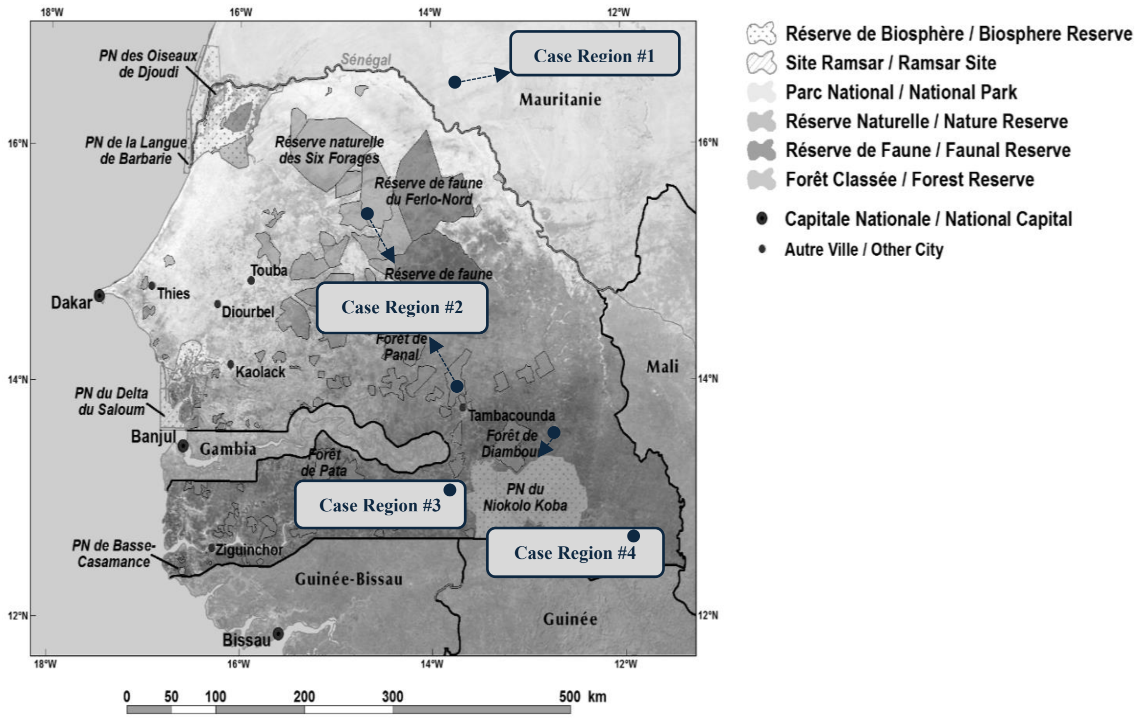

Figure 2.1 Topographic map of Senegal adapted from United States Agency for International Development (USAID), United States Geological Survey (USGS) and Republic of Senegal (Atlas, 2018.) that provides visual characteristics indicating ecological characteristics and four case study regions of north- and southeastern regions of Senegal. Regional bases within each case represented by dark blue dot and arrow: case region #1 – Ndioum, case region #2 – Dahra Jolof to Koumpentoum, case region #3 – Gouloumbou to Velingara, case region #4 – Kedougou.

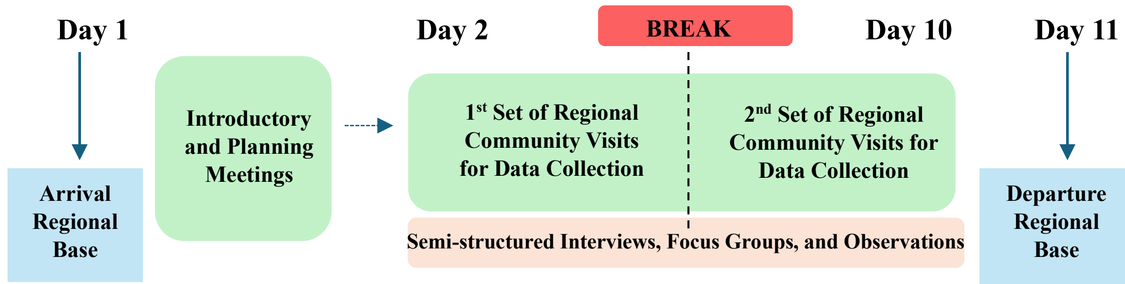

Figure 2.2 Timeline of in field research data collection of semi-structured interviews, focus groups, and observations. For each regional base Day 1 reserved for customary greetings and introductions with an informal meeting and meal. Day 2 – 8 included visits to surrounding communities within the defined regional base area for semi-structured interviews and participatory observations. A local individual was selected to prepare the meal for participants and surrounding community members which served to establish a repour with the community and potential interviewees. In addition to the meal, a local form of tea will be supplied to engage in customary tea making rituals. Day 9 was reserved for travel day from regional site to capital city of Dakar.

Table 2.1. Sample transcript excerpts labeled by using primary codes and descriptions referenced from codebook for thematic analysis of semi-structured and focus group transcripts.

Code Name	**Code Description**	**Example**
Adaptive Strategies	activities or plans informally or formally developed to maintain livelihood practices against challenges or obstacles	"In our villages also, we make our own corridors and tell people not to farm there and that can help us to go in the foret clase or join the principal corridor. The corridors are very important, they facilitate our access into the protected forest, and we take the corridors when we want to move from one village to another. The also help to avoid conflicts between farms and herders. "
Stressors	internal or external stimulus or actions which cause a strain/tension on pastoral and agricultural livelihood practices	"It is because people have cut all the trees, and don't plant trees. Now, the desert is getting bigger. The lack of water has affected the animal production because there is less grass for food for animals. The herders and farmers are both suffering."
Communal Resources	natural resources (i.e., water, land, trees) traditionally shared among community members	"There used to be more rain in the past than today. The lands become poorer. We are using a lot of chemicals on our land, which burns the soil. But we have no choice. The soil is dead, and we need fertilizer to reinforce it."
Tensions	individual participants distinct perspective (viewpoint) on the tensions between pastoralists and farmers (characteristics or identification of specific pressures)	"We don't have the same objectives and herders should have their side and farmers their side, but the cause is farms will never move and animals move a lot even if you supervise them, they go and destroy farms sometimes unknowingly."
Silvopasture Perceptions	individual participants awareness (understanding) and interpretation of the practice of silvopasture	"It will help a lot to have trees that produce food for animals and animals that produce manure for the farmer."
Utility	comprehensive benefits and/or challenges of the integration of silvopasture practice	"How to protect the trees from animals while they are young will be challenging."
Open Codes	additional information of interests beyond initial codes listed	"There are quite a few difficulties that happen to us such as the lack of water, the heat, but also, the scarcity of food that forces us to travel a little further."

Table 2.2. Key internal and external adaptive strategies identified among case region communities to mitigate pressures and reduce competition within commons land in Senegal.

Senegal Case Region Adaptive Strategies
Geographically Non-Specific Strategies
Seeking non-traditional livelihood activities
Using permanent transhumance corridors
Strategies Specific to Northern Case Region
Altering herding activity movements
Developing pastoral units and organizations
Supplementing livestock food sources
Transitioning from herding to other livelihoods activities
Strategies Specific to Central Case Region
Creating and securing farm borders
Diversifying economic opportunities
Depending on high farm inputs for productivity
Strategies Specific to Southern Case Regions
Increasing economic opportunities
Conserving and protecting natural resources
Engaging in agroforestry techniques and practices

Chapter III: Missouri Agricultural Producers' Interest in Woodland Silvopasture Adoption – Perceptions, Practices, and Barriers

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Abstract

Over one – third of forested land in Missouri (2 million hectares) is privately owned, with on average 0.92 million hectares grazed by livestock. Grazing of livestock in unmanaged forestland is discouraged due to potential adverse ecological effects and decreased animal productivity. Though, many Missouri livestock producers, particularly with smaller acreage, graze such forested areas out of necessity and convenience. Silvopasture has the capacity for ecological, economic, and social benefits by intentionally managing trees, forage, and livestock, with the potential to mitigate the adverse effects of unmanaged grazing. This study aimed to assess the current practices and perceptions of woodland silvopasture adoption among producers through a statewide mixed-mode survey distributed mid-February – May 2022. With 400 responses (response rate 6%), the majority of respondents indicated engagement in some level of livestock grazing and forest management activities. About 16% of respondents indicated incorporating silvopasture management on their farms. More than half of respondents indicated they did not incorporate silvopasture management currently or in the past, with 18% of respondents uncertain whether they currently or previously implemented silvopasture. This suggests a knowledge gap between current management practices and silvopasture application among producers. Approximately 53% of respondents indicated an interest in the implementation of woodland silvopasture, which was significantly ($P < 0.01$) influenced by respondents' attitudes towards woodland silvopasture's perceived benefits and opportunities. This indicates Missouri producers within the survey population as potential candidates for adoption of woodland silvopasture due to interests, current practices, and attitudes, with further education towards producers' understanding of woodland silvopasture establishment and management strategies.

Introduction

Silvopasture, an agroforestry practice, involves the intentional integration and intensive management of trees, forage, and livestock. Silvopasture systems have the capacity to provide ecological, economic, production, and social benefits, including enhanced ecosystem services (Beckert et al., 2016; Pent & Fike, 2021; Udawatta et al., 2022), diversification of the landscape (Gabriel, 2018), improved whole-farm management, reduction in environmental stress on animals (Brantly 2013), improved animal performance (Kallenbach et al., 2006; Kendall et al., 2006), and increased revenue diversity (Jose & Dollinger, 2019). Silvopasture also can create a microclimate that produces higher forage nutritive value, provides consistent shade for livestock, and maintains animal productivity (Kallenbach et al., 2009; Ford et al., 2019b; Pent & Fike, 2019; Kremen, 2020). Despite the potential for such benefits, the adoption of silvopasture systems remains low, likely due to lack of awareness of these benefits, establishment and management challenges, inadequate technical assistance and resources, limited research studies and demonstration sites to showcase application (Mayerfeld 2016; Orefice et al., 2017).

Within temperate agroforestry there are two primary types of silvopasture: plantation silvopasture, the planting of trees into open pastures, and woodland silvopasture, the thinning of existing tree stands to increase the availability of light for forage growth (Wilkens et al., 2022b). Woodland silvopasture specifically seems to be a preference for establishment on privately owned land (Wilkens et al., 2022b). In addition to other silvopasture benefits, woodland silvopasture offers the opportunity to increase grazable acres and incentivize improved woodland management and be an alternative to unmanaged forests or land-clearing for pastures. Research into the implementation of woodland silvopasture has slowly grown throughout the United States, with the advocation for climate smart agricultural practices, alternative grazing methods, and sustainable agriculture (Asbjornsen, 2023). However, the adoption and implementation of woodland silvopasture remains hindered, mainly due to adverse perceptions on the risks of livestock in wooded areas, limited knowledge of best management practices, establishment barriers, and management challenges in the application of the practice (Lawrence et al., 1992; Orefice et al., 2017; Ford et al., 2019a; Smith et al. 2022).

Adverse perceptions among natural resource professionals have persisted as an obstacle to the adoption of woodland silvopasture, driven by historical opposition among agricultural practitioners, natural resource professionals, and conservation organizations (Mayerfeld et al., 2016; Ford et al., 2019a). Since the 1950s, professionals have discouraged the grazing of livestock within wooded areas, with campaigns and extension efforts focused on persuading landowners against the practice and reducing pasturing in woodlands (Williams, 1951; Abbott, 1954; McQuilkin & Scholten, 1989). Research has shown negative impacts of unmanaged woodland grazing on timber stand health and natural tree regeneration while focused on residual tree health and productivity, establishment costs, land suitability, and livestock performance (Den & Day, 1934; Ahlgren et al., 1946; Sluder, 1958; Stoeckeler, 1959; Linnartz et al., 1966; DeWitt, 1989; Belsky & Blumenthal, 2002; Borman, 2005). Furthermore, conservation agencies and organizations have raised concerns about the negative impacts of livestock within woods on wildlife and aquatic habitats, endangered and threatened species, and soil health and water quality (Arbuckle, 2009). Such positions strengthened the assumption that livestock grazing and forest management are incompatible, resulting in policy, which further separated agricultural production and woodland management.

Producers continue to show interest in the practice of woodland silvopasture, which presents an opportunity to promote implementation of the practice as an approach to restoration and management of privately-owned forested lands (Mayerfeld et al., 2016; Wilkens et al., 2022a; Mayerfeld et al., 2023). Moreover, the demand for grazing within forested acres for shade has increased substantially in recent years as extreme climatic events (i.e., heat waves, prolonged droughts, fire, and rainstorms/flood) have become frequent and intense. This is specifically present in the Midwest (Missouri, Iowa) and Great Plains (Kansas, Oklahoma), resulting in a rise in heat-related livestock losses (Doll et al., 2017; Upadhaya & Arbuckle, 2021). Heat stress in livestock results in suppression of the immune system, reduction in appetite, decreased fertility, lower milk production, and premature cattle mortality; thus, producers seek to capitalize on existing naturally shaded areas to prevent such effects.

Historically, the landscape of the Midwest consisted of oak savanna and woodland ecosystems, managed by fire, that supported an agrarian lifestyle and provision of ecosystem services (Nelson, 2004; Hanberry et al., 2017). However, these ecotypes diminished over time with colonial expansion, which incited overgrazing of introduced domestic livestock, intensification of agricultural crop production, and suppression of fire (Benac & Flader, 2004). These unsustainable management practices changed the historic oak savanna and woodland ecosystem to extensive cropland and pastureland with forested areas on privately owned land. Presently, Missouri has roughly 11 million hectares of farmland, which supports a robust livestock industry with an average 4 million head cow/calf population (USDA NASS, 2022). Additionally, the state has 6 million hectares characterized as forested land, with over one-third present within privately owned farms. An estimated 0.92 million hectares within privately owned forested land is grazed by livestock, with limited information available on grazing management practices within these acres (Forest Service, 2021; Missouri Department of Conservation, 2023). With the demand and interest among producers, the potential ecological advantages for woodland silvopasture to facilitate woodland restoration and management, and the continued reluctancy by natural resource professionals to support the practice, further information is necessary to characterize the current state of *livestock in the woods* in Missouri. Therefore, this project aims to assess the current practices and perceptions of benefits and barriers to adoption among agricultural producers in Missouri with the following objectives: (1) evaluate current livestock grazing and woodland management practices among producers in Missouri; (2) assess the understanding of and attitudes towards woodland silvopasture among producers; and (3) identify the relationships between current management practices, perceptions of woodland silvopasture, and subsequent interest in implementation of the practice.

Materials and Methods

Survey Design and Distribution

Researchers within the University of Missouri Center for Agroforestry (UMCA; Columbia, MO, USA) developed a survey targeting agricultural producers within the state of Missouri. The mixed-mode (electronic and mail) survey was designed to elicit responses to assess the producers' current agricultural production and livestock management systems, forestland ownership and management, perception of woodland silvopasture system, and respondent demographics (Dillman, 2011; Wilkens et al., 2022a). To measure these elements, participants were prompted to answer multiple-choice and open response questions. Participants were provided with a visual aide and brief description of woodland silvopasture to standardize comprehension (Wilkens et al., 2022a) and subsequently indicate perceptions of different aspects of woodland silvopasture through Likert scales. These questions aimed to measure respondents' agreement or disagreement (1 = Strongly disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; and 5 = Strongly agree) with perceived benefits and barriers to woodland silvopasture adoption and prioritization of potential benefits (1 = Low priority; 2 = Somewhat priority; 3 = Neutral; 4 = Moderate priority; and 5 = Essential priority). A binary yes-no question was included to measure the interest of producers in implementing woodland silvopasture management, followed by a Likert scale (i.e., 1 = Extremely unlikely; 2 = Unlikely; 3 = Neutral; 4 = Likely; and 5 = Extremely likely) to determine the likelihood of statements to influence interests to adoption.

Following the initial design of the survey instrument, pilot peer tests via focus groups (n = 2) were administered among in-person (n = 4) and virtual participants (n = 6) to refine and evaluate the effectiveness of the survey and ensure applicability (Collins, 2003; Perneger et al., 2015). Feedback from these groups was used to strengthen and refine the survey design. The finalized version was translated to Spanish through the University of Missouri-Columbia Cambio Center to increase accessibility in distribution to respondents. An introductory paragraph preluded the survey with language to establish informed consent for the Institutional Review Board (IRB, 2037123 MU).

Distribution and Data Collection

Between mid-February and mid-May 2022, the mixed-mode survey was disseminated asynchronously in partnership with the Farm Journal, a national agricultural media content organization, and its Trust in Food Initiative, a social-purpose initiative designed to accelerate the transition to sustainable and resilient agricultural systems. Surveys were distributed in a simple random sample design within the Farm Journal affiliates' electronic network and existing mailing lists. To expand the distribution of the electronic survey, Lincoln University and University of Missouri Extension networks were accessed to target rural and underrepresented populations. Criteria for inclusion in the sample population included being at least 18 years of age and living and/or operating land within Missouri. Electronic surveys were administered through Qualtrics (Qualtrics, Provo, UT) mid-February – late April 2022, and mailed surveys were delivered with a pre-paid return envelope and post card mid-March – mid-May 2022. A total of 35,774 survey e-blasts were distributed through electronic email deployments and 2,994 surveys through existing mailing lists, along with social media networks, to generate a sample population of livestock producers and landowners who engaged in common Missouri agricultural enterprises. Social media contact consisted of Facebook sponsored biweekly posts and internet advertising markets (Drovers RON Native, Drovers RON display, E-News Metrics, Drovers Daily Module) published on the Farm Journals' websites. To incentivize participation, individuals were provided an option to be directed to a secure Qualtrics link to input information for survey raffle and/or provide contact information. This ensured contact information was disconnected from survey responses to maintain survey anonymity. Non-responders were prompted by routinely scheduled ad-markets for routine publication for the electronic surveys for mailed survey responders, a follow-up reminder post card was mailed 18 days following the anticipated date of the initial survey mailing to addresses.

Statistical Analysis

Unanswered responses in surveys were marked as missing data values, and results were analyzed collectively through statistical analysis software SAS 9.4 (SAS Institute Inc., Cary, NC) Descriptive statistics were applied to summarize categorical and continuous variables and assess cumulative frequency distributions. Categorical variables were examined through one-way frequency tables, and continuous variables were analyzed through measures of central tendency. Cross-tabulation with chi-square was utilized to describe the relationship between two categorical variables. To further evaluate the relationship among multiple response choices, variables were assessed with a multiple response analysis to obtain frequencies (Fehd, 2004).

Likert scale responses were considered ordinal data and examined using mode as the central tendency measure (Allen & Seaman, 2007). Categorical and continuous variables were analyzed with multivariate logistic regression to examine the relationship between predictor variables and the response variable. Chi-square equality of means test at $\alpha = 0.05$ was used to determine significance. Variables unselected or indicated to have no linear combination by non-significant p-values with other variables were removed from the model. Explanatory variables with significance ($P < 0.05$) were used in the decision tree regression model (Stokes & Staff, n.d.).

To explain the binary indicators (yes|no), a decision tree model was used to form a regression tree structure. This allowed visual representation of participant responses towards decision-making of likelihood to implement woodland silvopasture. Logistic regression was used to initially examine the relationship between categorical and continuous variables on the response variable, adoption of woodland silvopasture. Variables identified to be significant were subsequentially analyzed in a decision tree regression model to further examine the relationships between significant predictor variables and respondents' interest in implementing woodland silvopasture management. Following formation of decision tree, a comparative analysis was conducted through tree (rpart) package to validate the SAS model (Therneau et al., 2023).

Results

Respondents' Demographic Profile

A total of 400 responses were collected via electronic (*n* = 228; 0.6% response) and mailed surveys (*n* = 172; 6% response). Among the survey respondents, over 70% provided demographic characteristics (Table 3.1) with most respondents characterized as male (84.9%), between the ages of 66 – 75 (33.1%), who identified as White or European American (93.6%), with a bachelor's degree as the highest level of education received (31.8%), and Gross Income of their farm average over $100,000 (28.2%). Among demographic respondents, 46.3% reported farming accounted for most of the annual household income within the last five years, while 49.8% reported it did not.

Over 95% of respondents reported experience in agriculture and forest management, with less than 5% reporting experience in solely agriculture. Ninety-nine percent of respondents reported they owned land, with the average respondent owning either 101 – 250 acres (27.9%) or 251 – 500 acres (25.5%). Around 13% of respondents owned land between 0 – 100 acres (13.3%), while roughly a third reported owning land greater than 501 acres (32.1%). In addition to owning land, greater than 70% of respondents reported leasing land, with the majority of land leased between 0 – 9 acres (21.1%).

Over 85% of survey respondents reported the production of agriculture and forest products for personal household consumption (92.0%) and/or commercial production (86.9%; Table 3.2). The primary agricultural product was livestock for meat production for personal consumption (83.7%) and commercial production (79.7%). Annual vegetables (49.3%) were the second most reported agricultural product for personal consumption, though only 3.5% reported for commercial production. Twenty-one percent of respondents reported personal timber production, while 15.8% reported commercial timber production. Non-timber products were reported by 17.8% of respondents for personal consumption, but only 2.3% reported production for commercial purposes. Less than 1% of respondents reported the production of timber or non-timber products for personal or commercial use without forestry experience.

Livestock Grazing and Woodland Management Practice

Survey respondents (n = 400), reported beef cattle (93.3%) were the dominant animal type managed in individuals' livestock operation, which is consistent with the agricultural profile of Missouri. Poultry (15.0%) was the second most reported animal among respondents. Other animals included in livestock operations were hogs (6.5%), sheep (5.5%), dairy cattle (4.3%), and goats (3.5%). Less than 5% of respondents reported the management of other livestock including donkeys, whitetail deer, horses, llamas, rabbits, gamebirds, and catfish. Three percent reported not owning or having livestock within their operation.

Livestock grazing was predominately reported around the months of April (84.6%) to November (79.6%) with majority of grazing (94.3%) in the summer months, [May, June, July, August], and a few all year-round. The predominate forage species reported within grazing systems were cool season grasses such as tall fescue (90.6%) and orchardgrass (50.5%), legumes such as red clover (62.5%) and white clover (52.6%), and hay or mixed grass hay (73.7%) as an additional feed option. Fewer warm season grass species were reported, which were primarily warm season annuals (18.4%) and big bluestem (10.7%). The majority of total survey respondents (52.3%) reported the incorporation of rotational grazing between different open pastures as a grazing management practice within their livestock operation. Rotational grazing between pasture and woodlands was the second highest reported among respondents (35.1%) as a grazing management practice. Additional grazing management practices reported were stockpile grazing in pastures (33.1%) and continuous grazing in open pastures (32.8%). Confined feeding (45 or more consistent days; 24.0%), managed intensive rotational grazing (8 or more paddocks; 21.5%), and woodland and forested grazing (20.2%) were reported as well. Fewer respondents (1.0%) reported the inclusion of other grazing management practices such as flash grazing through wooded stream corridors and grazing within crop fields.

More than 96% of total survey respondents recorded the presence of owned and/or leased wooded or forested land on their property. Respondents estimated the proportion of wooded and/or forested land was mostly 0 – 25% (60.3%) of their total land, followed by 26 – 50% (29.0%). Approximately 20.2% of respondents reported owning or leasing land that was 51 – 75% wooded acreage, and 17.8% managed land that was primarily (greater than 76%) wooded land. Of the respondents who recorded the presence of wooded land on owned and/or leased property, a majority also reported managing beef cattle (90.5%).

Respondents reporting wooded acres were also asked to describe the acres' structure and understory vegetation, and the incidence of grazing within the areas. Among respondents with wooded acres (n = 386), the most reported understory structure was moderate levels of vegetation under tree canopy cover levels characterized as lightly wooded (Table 3.3). Respondents who reported owning and/or leasing lightly wooded tree canopy covers tended to describe the vegetation as medium to lush with 16% reporting little to no or compact vegetation. As the percentage of tree canopy cover increased above 25%, respondents indicated a higher percentage of bare ground present within thickly wooded (25.0%) and heavily wooded tree cover (40.9%). More respondents tended to describe the understory vegetation within tree canopy covers over

25% with increasing moderate level vegetation by 25%, though dense level vegetation was reported to increase by 8.3%.

More than 45% of respondents indicated the practice of grazing within wooded acreage owned and/or leased, with the highest incidence of grazing reported within lightly and moderately wooded acres. Grazing within moderately wooded acres was 6% less reported than lightly wooded acres but medium to lush vegetation tended to be reported 11% more in the understory. Lightly and moderately wooded acres also were the lowest reported for thick to compact vegetation (12% and 7% respectively) compared to tree canopy cover above 26%. Less than 50% of respondents reported grazing within tree canopy cover above 26%, though with over 50% of respondents characterizing the understory vegetation as medium to impenetrable. Of the respondents who reported grazing in the woods, heavily wooded acres were reported the least (31%) and mostly characterized by little to no vegetation within the understory (41%). Heavily wooded acres had about 20% more indication of impenetrable vegetation within the understory, compared to the highest reported lightly and moderately wooded grazing conditions. Respondents who indicated grazing within wooded acreage were most likely to practice rotational grazing between pasture and woodlands, with the highest percentage of respondents grazing within tree canopy cover under 25% (Figure 3.1). Woodland and/or forested grazing was prevalent across all levels of canopy cover but tended to be less reported than rotational grazing. Tree canopy cover above 50% was the least reported for grazing among respondents, though was reported by less than 15% of respondents for woodland and rotational grazing.

Among the wooded acreage owned and/or leased, respondents (94.5%) identified engagement in forest management activities. Within the last 10 years, the prominent forest management activity reported was mechanical and physical clearing of brush (57%), followed by commercial logging (40.3%). Respondents also reported conducting chemical removal of invasive species (30.1%), non-commercial thinning - timber stand improvement (TSI, 22%), prescribed burning (11%), and cultural clearing of brush (7.5%). Additional practices indicated were grazing with sheep and goat to clear understory and brush, harvesting of logs for firewood, undergrowth mowing, and cleaning of fence row. Figure 3.2 shows the reported level of grazing within wooded acreage, with the highest incidence of rotational grazing within woods managed through mechanical and/or physical clearing of brush (23.1%). This forest management activity also had the highest reporting of woodland and/or forested grazing (14.8%). Grazing was reported within wooded areas that received no management, though less than 5%. Of respondents asked to report on the incorporation of silvopasture management on their farm, more than 60% of individuals indicated they do not currently or have in the past implemented woodland silvopasture. Sixteen percent indicated they had practiced silvopasture, with 18% unsure if they practiced woodland silvopasture.

Producers' Perceptions, Attitudes and Barriers toward Implementation of Woodland Silvopasture

Figure 3.3 shows an overall favorable perception towards woodland silvopasture among survey respondents. Over 50% of individuals indicated agreement with the integration of livestock in woodlands to be suitable for their operation, and 62% reported disagreement that the integration of livestock in woodlands is ecologically detrimental. Furthermore, majority of respondents agreed that livestock are a useful woodland management tool (54%) and integration of livestock in woodlands is ecologically beneficial (45%), with over 18% of respondents strongly agreeing with those statements. More than half of respondents remained neutral in the agreement or disagreement that the integration of livestock in woodlands is different than woodland grazing.

Many respondents recognized the perceived benefits of woodland silvopasture (Figure 3.4), with the benefit of maximizing production acreage as the most agreed upon. A similar trend is shown in Table 3.4 with the priority of perceived potential benefits of woodland silvopasture. Majority of respondents tended to prioritize perceived production and environmental benefits, with the highest priority of improved timber value (48.2%) and reduced seasonal environmental stress for livestock (47.6%). Among respondents, economic and social benefits tended to be reported as neutrally prioritized. Within social benefits, more respondents indicated expanding recreational services as the lowest priority compared to the other benefits.

Respondents' agreement or disagreement to the establishment and management barriers of woodland silvopasture are reported in Table 3.5, with a uniform trend of neutrality throughout the Likert-items provided. Respondents' agreement agreed that financial investment (41.9%), required thinning of forest (40.1%) and labor and time management (44.7%) influenced their likelihood of implementing woodland silvopasture. Individuals also agreed that their limited knowledge of woodland silvopasture systems (38.5%) and the added requirement for forest management (37.0%) were key barriers that discouraged adoption. Most individuals were impartial to indicate conservation program restrictions (53.6%) and land ownership and tenure (47.8%) as barriers to woodland silvopasture establishment, but over 20% of respondents agreed these were barriers. Though respondents tended to be impartial or agree with the barriers to establishment and management, 12% of individuals strongly agreed with labor and time management as a barrier and strongly disagreed with having minimal animal experience to be a barrier to managing woodland silvopasture systems.

Woodland Silvopasture System and Adoption

The majority of respondents (52.7%) reported a willingness to implement woodland silvopasture management on their farm or land, while less than fifty percent (47.3%) indicated an unwillingness to implement woodland silvopasture management. Less than 1% selected neither option. A logistic regression indicated that none of the demographic variables significantly influenced respondents' interest in implementing woodland silvopasture management ($P = 0.15$). Neither the production of agriculture and forest products for personal or commercial use significantly influenced the interest of implementing woodland silvopasture among respondents

($P > 0.39$). Collective categorical variables related to livestock animals within an operation, months of grazing, individuals' ownership or lease of land, and forage type within the operation did not impact the willingness to adopt woodland silvopasture (Table 3.6). Individual variables including feed byproducts were shown to be significant in impacting the willingness of implementing woodland silvopasture management ($P = 0.03$). Also, respondents practicing rotational grazing ($P = 0.0005$) and confined feeding ($P = 0.05$) within their operations were found to be more willing to implement woodland silvopasture compared to respondents who engaged in rotational grazing between open pastures, continuous grazing, and forested grazing.

Whether or not a respondent identified ownership of woodlands within their property did not impact the willingness to adopt woodland silvopasture, however the proportion of woods and forests within the property did have an impact ($P = 0.04$). Moreover, the level of tree canopy cover of the woods owned ($P < 0.001$), woodland management practices by the respondent ($P < 0.0001$), and identified forestry experience of the respondent ($P = 0.009$) affected the willingness to adopt woodland silvopasture. Respondents who indicated the ownership of land with moderately wooded (11 – 25%) and thickly wooded (26 – 50%) acres were more likely to express interest in implementing woodland silvopasture management ($P < 0.05$). In addition, respondents that reported engagement in forest management activities within their forested acreage showed a willingness to adopt woodland silvopasture ($P < 0.0001$), specifically thinning ($P = 0.009$), mechanical ($P = 0.0001$). Respondents' level of agriculture experience did not affect their willingness to adopt woodland silvopasture, however their level of forestry experience did impact their willingness ($P = 0.0083$), with 15 – 24 years of forest management experience standing out as an impact factor ($P = 0.03$). Moreover, if respondents recorded presently, or in the past incorporating silvopasture management on their farm significantly impacted adoption $P < .0001$).

Overall, respondents who perceived the integration in woodlands as ecologically beneficial indicated a willingness to adopt woodland silvopasture ($P = 0.004$). Furthermore, respondents who perceived that the integration of livestock in woodlands was not suitable for their operation ($P < 0.0001$) influenced their likelihood of implementing woodland silvopasture management (Table 3.7). Respondents who agreed with the perceived benefits of woodland silvopasture maximized production acreage ($P = 0.007$), improved animal health and performance ($P = 0.02$), and offered wildlife habitat restoration ($P = 0.01$) were also more likely to indicate a willingness to adopt woodland silvopasture. Furthermore, woodland silvopasture opportunities found to influence likelihood of adoption included forest health management ($P = 0.02$), recreational services ($P = 0.05$) and increase pasture management ($P = 0.02$). Minimal animal experience among responders also influenced the likelihood of silvopasture adoption ($P = 0.01$). Additionally, potential environmental impact ($P = 0.006$), feasibility of establishment ($P = 0.03$), lack of interest in woodland silvopasture, $P < 0.001$), and lack of technical assistance or informational trainings, $P < 0.001$) influenced the willingness to adopt woodland silvopasture (Table 3.8).

Decision Tree Model

The decision tree output diagram (Figure 3.5) visually presents the probability of categorical and continuous variables to influence the respondents' interests in the implementation of woodland silvopasture. More than 50% respondents indicated a likeliness to implement woodland silvopasture management on their land, and 45% reported an unlikeliness to implement woodland silvopasture management (Figure 3.5). Of those likely to implement woodland silvopasture management, 67% reported increasing pasture management influenced their interest in practice implementation. Thirty-three percent of respondents who reported increasing pasture management as some priority benefit indicated they were uninterested in the implementation of woodland silvopasture management. Respondents (84%) most likely to not perceive increasing pasture management as a priority benefit indicated they were unlikely to implement woodland silvopasture management on their land, and 16% reported they would be likely.

Majority of respondents who indicated willingness to implement woodland silvopasture also reported not previously practicing silvopasture, or unsure if have practiced in the past. Over half of these respondents (59%) were likely to implement woodland silvopasture management, and 41% were unlikely to implement woodland silvopasture management. Fewer respondents reported currently or previously incorporating silvopasture on their farm with 97% of these respondents likely to implement woodland silvopasture management (Figure 3.5). Less than 3% of those who have or in the past incorporated silvopasture management indicated they were unlikely to implement woodland silvopasture management. The perception of integrating livestock in woodlands as ecological beneficial was another determinant influencing practice implementation. Seventy-two percent of respondents that agreed with this perception reported they were likely to implement woodland silvopasture management, while 28% reported they were unlikely to implement. Respondents within neutral or disagreement with this perception (68%) were unlikely to implement woodland silvopasture management, though 32% indicated a likelihood to implement the management practice. Additionally, respondents' lack of interest in woodland silvopasture also tended to influence the implementation of woodland silvopasture.

Discussion

Respondents Demographic Profile

Through the survey, we reached our target population of typical conventional agricultural actors in the state of Missouri. Respondent demographics reported (Table 3.1) are consistent with the current profile and management practices reported within the 2017 Census of Agriculture Missouri State Profile, which suggests our response pool is representative of the target population of interest in Missouri (Kinder, 2015; University of Missouri Extension, 2015; USDA NASS, 2017). Among respondents, the primary agricultural product for personal consumption and commercial production was livestock meat production, with over 90% reporting the management of beef cattle within livestock operations. The National Agricultural Statistics Service reported Missouri ranks among the highest in US cattle inventory with 1.7 million behind #1 Texas (4.3 million) and #2 Nebraska (1.7 million), and within the top 10 states in sale of cattle and calves (2.0 billion), which supports the significant percentage of survey respondents in beef cattle livestock production (University of Missouri Extension, 2015; USDA NASS, 2015; Missouri Department of Agriculture, 2019). Since 2015, the cattle inventory within the state has grown to total 4.04 million head of cattle million to account for a substantial contribution to the cattle inventory within the United States (USDA NASS, 2022).

More than half of respondents reported utilizing a rotational grazing system between different open pastures, which aligns with the trend of improved grazing management practices reported throughout the state (University of Missouri Extension, 2018). The majority of grazing tended to be higher in the summer months, though native warm season grasses tended to be reported lower by respondents, commonly due to the change over time in pasture composition with introduced species (Kroth et al., 1977; Kinder, 2015). Thirty-five percent of respondents also indicated practicing rotational grazing between pasture and woodlands in combination with other grazing management within their operation, though 16% reported solely grazing between pastures and woodlands. Galleguillos (et al., 2018) reported a similar incidence among farmers interviewed within the upper Midwest engaged in woodland grazing practices. Few farmers indicated rotational grazing between pastures and woodlands, which allowed cattle access during a portion of the grazing season. More farmers reported continuously grazing within the woods, allowing cattle to freely graze without restriction between open pastures and woodlands throughout the growing season (April – October) (Galleguillos et al., 2018). In contrast, less than 10% of respondents within the present survey reported only practicing woodland or forested grazing. Within the survey of farmers in Wisconsin, farmers reasoned the grazing of woodlands to access more acreage for grazing, providing shelter, management of brush, and decrease of property taxes (Galleguillos et al., 2018). This indicates Midwest farmers, depending on the geographic area, are allowing access of woods to livestock, whether in combination with open pasture systems or exclusively forest grazing. These Midwest producers can be a potential population focus to provide education towards the integrative grazing management practices such as woodland silvopasture since presently engaged in variations of forest grazing.

The majority of respondents recorded the presence of wooded land within their property, which is in alignment with census data describing wooded areas within privately owned farms in Missouri (USDA NASS, 2017; Forest Service, 2021). Most respondents reported conducting forest management activities within the last 10 years, with the mechanical and physical clearing of brush as the most reported. Respondents also reported on the production of timber and non-timber products for personal consumption, and commercial production. We can infer that Missouri livestock producers in the survey population actively engage in some form of forest management, which contradicts the assumptions that livestock producers in Missouri do not prioritize management of their woods. This presumption has persisted, partly due to the percentage of forested land privately-owned (85%) and a simultaneous lack of documented forest management plans (FMPs). Though there is an absence of published data to support this presumption, these attitudes continue to be displayed within governmental publications and research notes, extension guides, and informal conversations with outreach professionals (Missouri Department of Conservation, 2003). With the high percentage of producers (> 90%) reporting participation in forest management, the survey captures insight to challenge these assumptions, assess the extent of forest management, and highlight areas of improvement.

Previous reports and articles have estimated that 35% of forest within the Central Hardwood Region (Michigan, Wisconsin, Minnesota, Missouri, Ohio, Indiana, Illinois, and Iowa) are being pastured without intensive management, with Missouri as the highest in wooded hectares (0.92 million) pastured (Garrett et al., 2004). Moreover, a survey within rural counties of Missouri reported that 68% of woods were grazed (Hershey, 1991). Relative to the limited data, our study has shown producers are grazing livestock within wooded and forested lands, though in different grazing management practices (Figure 3.1). Most respondents reported grazing within canopy covers producing less than 25% of shade with medium to lush vegetation available (Table 3.3), though respondents did report some form of grazing within denser canopy covers. Within these canopy covers, grazing indicated by respondents consisted of rotational grazing between pastures and woodlands and woodlands or forested grazing. Producers who indicated practicing rotational grazing between pasture and woodlands, and the mechanical and non-commercial thinning forest management practices were found to significantly ($P < 0.01$) influence the likelihood of implementing woodland silvopasture (Table 3.6). This further supports the need for investment into Missouri producers as potential adopters of woodland silvopasture management as engaged in transferable practices.

More than half of survey respondents indicated they did not practice woodland silvopasture currently or in the past, and less than 20% indicated they were unsure if they do or have engaged in the practice. Only 16% of survey respondents indicated they currently, or in the past, practiced woodland silvopasture. Although, 35% of respondents reported practicing rotational grazing between open pastures and forested acreage, and most of respondents neutrally perceived that the integration of livestock in woodlands is different than woodland grazing (Figure 3.2). This highlights a discrepancy among individuals' ability to recognize the practice of woodland silvopasture. Thus, we can infer that respondents fall within the following groups: (1) individuals who do not practice woodland silvopasture because they do not own woods or property, nor graze their livestock within woods, (2) respondents who participate in woodland grazing without intentional management and therefore do not practice woodland silvopasture, (3) producers who engage in grazing with applications of woodland management and think they are practicing woodland silvopasture, or those who are unsure if they are practicing woodland silvopasture, and (4) producers who are indeed implementing woodland silvopasture management. Fewer respondents indicated practicing woodland silvopasture, thus this data does not support that many individuals think they practice woodland silvopasture. This data showed respondents were more inclined to engage in management similar to woodland silvopasture, though not recognize it as such. These groups represent gaps, which persist among the classification or determination of what qualifies and is not considered woodland silvopasture and signifies the opportunity for producer outreach and education (Orefice et al., 2017).

Producers' Perceptions, Attitudes and Barriers toward Implementation of Woodland Silvopasture

Majority of respondents indicated an interest in the implementation of woodland silvopasture management. Moreover, a generally positive perception of woodland silvopasture persisted, supported by a consistency for respondents to indicate agreement with perceived potential benefits. This is consistent with reporting among other silvopasture adoption studies (Mayerfeld et al., 2016; Wilkens et al., 2022a). These studies also reported the management of livestock and forage within existing tree stands as a preferred method of establishment among landowners (Wilkens et al., 2022b). The reasoning for the preference was documented in these studies as improved long-term forest health and productivity, pasture relief, and access to forest management. Similar benefits were reported among respondents in this study with agreement on maximization of production acreage (Figure 3.3) and prioritization for forest health management, improvement of timber value, and increase pasture management (Table 3.3). Also, most respondents tended to prioritize the benefits of management of invasive species and reduce seasonal environmental stress for livestock (Table 3.3). Such benefits have been previously identified among producers and natural resource professionals within qualitative and quantitative studies (Mayerfeld et al., 2016; Orefice et al., 2017; Smith et al., 2022).

Though these benefits have been shown to be significant in influencing adoption of woodland silvopasture, barriers and challenges to the establishment and management of the practice have limited adoption and implementation of woodland silvopasture. Within this study, respondents strongly agreed that financial investment and the requirement of forest thinning were barriers to the establishment of woodland silvopasture. Also, respondents indicated labor or time management as a significant management barrier to woodland silvopasture. These barriers and challenges have been previously reported among non-industrial private landowners (Lawrence et al., 1992). These landowners indicated high establishment costs, along with livestock damage to trees or crops as the most frequently selected barriers (Lawrence et al., 1992). Furthermore, this study reported a lack of technical and educational support were disincentives to practicing agroforestry practices with livestock. Though incentive programs have been established through the United States federal government to support silvopasture, the programs are limited and contradict management practices for producers and landowners, thus creating difficulty to intensify their land, and experience higher financial risk, establishment costs, and constraints on credit when adopting new practices.

Beyond labor and financial constraints, respondents reported limited knowledge of systems, technical assistance, and minimal informational meetings as barriers to implementation of woodland silvopasture. A consistent challenge throughout the United States among the adoption of woodland silvopasture has been the advocation against the combination of trees and livestock among forestry and agriculture advisors because of potential adverse effects on tree stands and animal productivity (Mayerfeld et al., 2016). The reluctancy has continued among resource professionals to endorse livestock access to woods, which has limited training and diminished the capacity for natural resource professionals to advise producers and landowners interested in the practice. This ultimately has led to delays in technical assistance available for producers interested in silvopasture (Mayerfeld et al., 2016). Previous studies have assessed the attitudes of agricultural and natural resource professionals, which concluded resource professionals were more likely to be reluctant to investigate or advocate silvopasture if their past training, messaging and recommendations consistently opposed any combination of livestock and trees (Mayerfeld et al., 2016; Orefice et al., 2017). Also, the lack of support from agricultural extension organizations, and limited professional interactions tended to influence the capacity of resource professionals to assist producers interested in silvopasture (Orefice et al., 2017). To support the implementation of woodland silvopasture it is necessary to provide resource information, fix misconceptions, and increase knowledge to producers and landowners (Dyer, 2012; Orefice et al., 2017).

Conclusion

Survey results presented respondent demographics that were consistent with current profile and management practices among livestock producers in Missouri. Survey findings also showed that majority of respondents were engaged in some level of grazing and forest management practices, which contrast informal assumptions of forest management among producers. Most respondents were uncertain about whether practicing woodland silvopasture, which indicates a knowledge gap between theory and practice. Despite this, majority of respondents expressed an optimistic attitude towards woodland silvopasture, indicating interest in the adoption of the practice. Thus, Missouri's resource landscape, current management practices, and attitudes and interest signify an opportunity to engage producers within the survey population for implementation of woodland silvopasture.

Though producers have shown interest in woodland silvopasture, there is discrepancy between producers' interest, understanding of silvopasture, and application of the practice with significant knowledge gaps. To engage these potential adopters, it is necessary to address these knowledge gaps among producers and landowners by articulating a cohesive definition of woodland silvopasture in which clear delineation between woodland silvopasture and unsustainable woodland grazing, researching silvopasture establishment and management strategies, and educating natural resource professionals in woodland silvopasture establishment and management. This requires simultaneous review of past and current research into the practice, while addressing research gaps such as economics (inputs and outputs) of silvopasture production systems and region-focused management requirements. In conjunction with outreach and extension activities to facilitate dissemination of knowledge to producers and application of scientific research and findings. This warrants the development of long-term practical demonstration sites to facilitate the development of management recommendations, and transfer of knowledge to producers by outreach and extension programs. To further support producers with the adoption of woodland silvopasture involves educating natural resource professionals through educational programming and training to expand silvopasture knowledge, for engagement with and to provide technical assistance to interested producers. Furthermore, it requires collaboration between natural resource professionals in sharing knowledge and resources.

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Table 3.1 Frequency of demographic characteristics of Missouri producers on gender identity, age range, race and ethnic identity, level of education, and farm gross income.

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	242	84.6
n = 286	Female	41	14.3
Age	18 – 25	0	0
n = 286	26 – 35	9	3.2
	36 – 45	24	8.4
	46 – 55	27	9.4
	56 – 65	76	26.6
	66 – 75	94	32.9
	> 76 or 76+	53	18.5
Ethnic Identity	White or European American	266	93.7
n = 284	American Indian or Alaska Native	5	1.8
	Native Hawaiian or Pacific Islander	0	0
	Black or African American	1	0.35
	Hispanic/Latino	0	0
	Asian	0	0
	Other	1	0.35
Education	Some high school	5	1.8
n = 286	High school graduate (or equivalent)	70	24.5
	Trade or Vocational degree	12	4.2
	Some college (1-4 years, associate degree)	62	21.7
	Bachelor (BA, BS, AB)	91	31.8
	Masters (MS, MA)	29	10.1
	Higher Degree (MD, JD, PhD, EdD)	16	5.6
Gross Farm Income	Net loss/no income	10	3.5
n = 284	Less than $2,500	6	2.1
	$2,500 - $8,999	18	6.3

$9,000 - $29,999	37	13
$30,000 - $69,999	58	20.4
$70,000 - $99,999	26	9.2
$100,000 or more	79	27.8

Table 3.2 Frequency of agricultural products produced for personal consumption or commercial use among Missouri producers. Percentages represent a cumulative value of multiple responses and therefore do not equal 100%.

	Categories of Agricultural Products									
	Annual Vegetables	Cereals Grains	Perennial Produce	Non-Timber	Timber	Meat	Non-Meat	Hay	*Other Edible	**Other Non-Edible
	Percentage (%)									
Personal	49.3	13.6	10.8	17.8	21.4	83.7	22.6	19.1	1.5	9.6
Commercial	3.5	24.4	1.8	2.3	15.8	79.7	8.3	15.1	0.8	7.5

*Other edible products for ***personal consumption*** responses included: fish and beans; ***commercial production***: beans, pheasant, and quail
Other non-edible products for ***personal consumption* included: grazing, pasture, silage, grass, alfalfa, wool; ***commercial production***: grazing, pasture, silage, grass, alfalfa, flowers, non-fescue seed

Table 3.3 Respondents' description of tree canopy cover and understory vegetation levels indicated to being grazed by livestock.

Tree Canopy Cover	***Understory Vegetation within Wooded Acreage***			
	Bare	Moderate	Dense	Grazed (Yes | No)
	Percentage (%)			
Lightly Wooded (0 – 10%)	16.0	73.6	12.1	83.3
Moderately Wooded (11 – 25%)	10.4	84.2	6.6	77.2
Thickly Wooded (26 – 50%)	25.0	55.7	22.6	49.3
Heavily Wooded (56 – 100%)	40.9	29.4	31.7	31.3

Cumulative response frequency for forage levels: bare (little to no vegetation within the understory), moderate (medium to lush vegetation within the understory that is walkable with minimal to no touching of brush), and dense (thick/compact vegetation within the understory which is impenetrable without equipment).

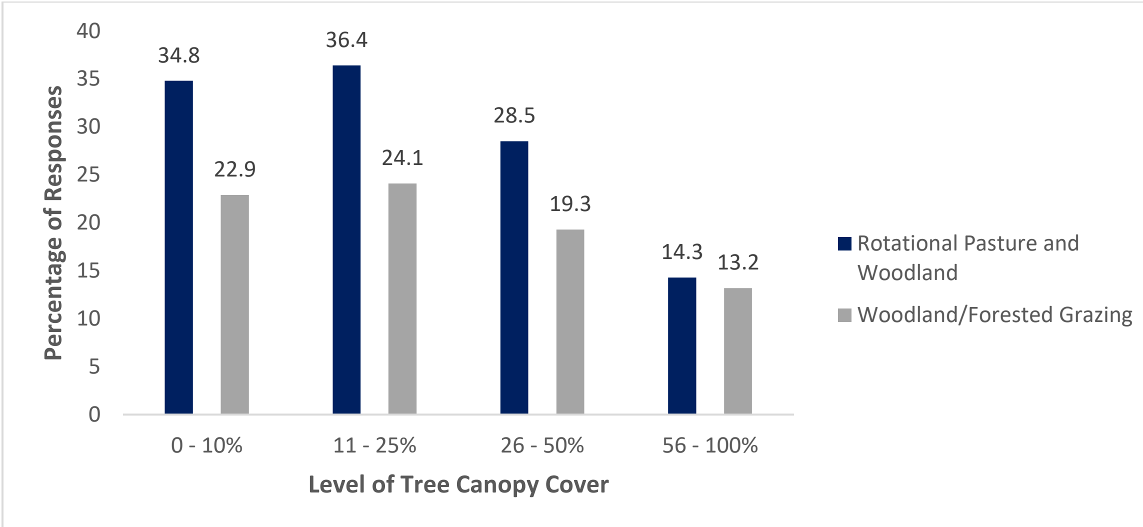

Figure 3.1 Percentage of respondents (*n* = 359) that reported engaging in rotational pasture and woodland grazing or woodland/forested grazing within various levels of tree canopy cover.

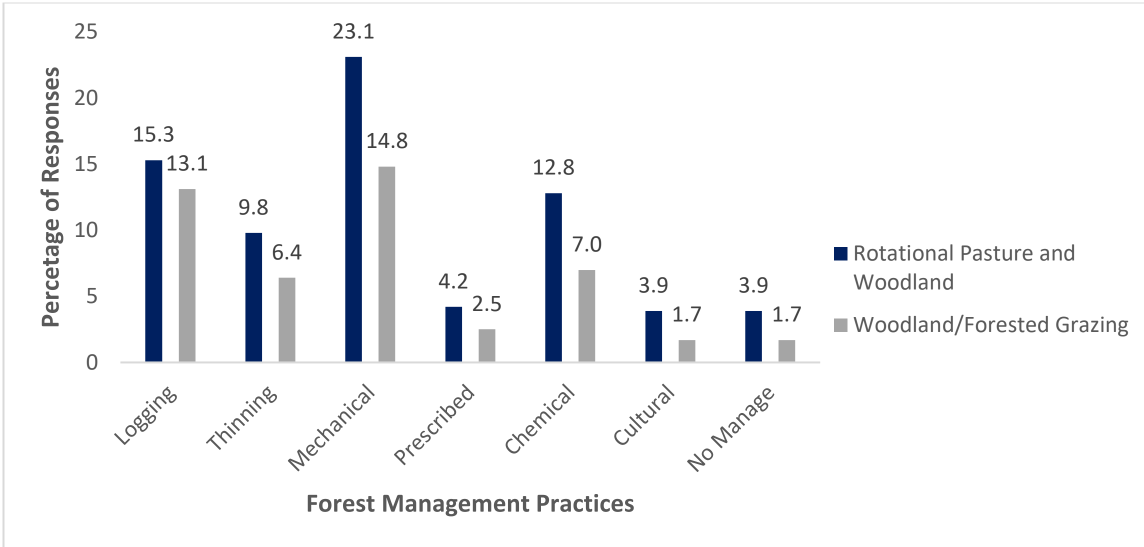

Figure 3.2 Percentage of respondents (*n* = 359) engaged in livestock rotational and woodland grazing practices and practicing forest management.

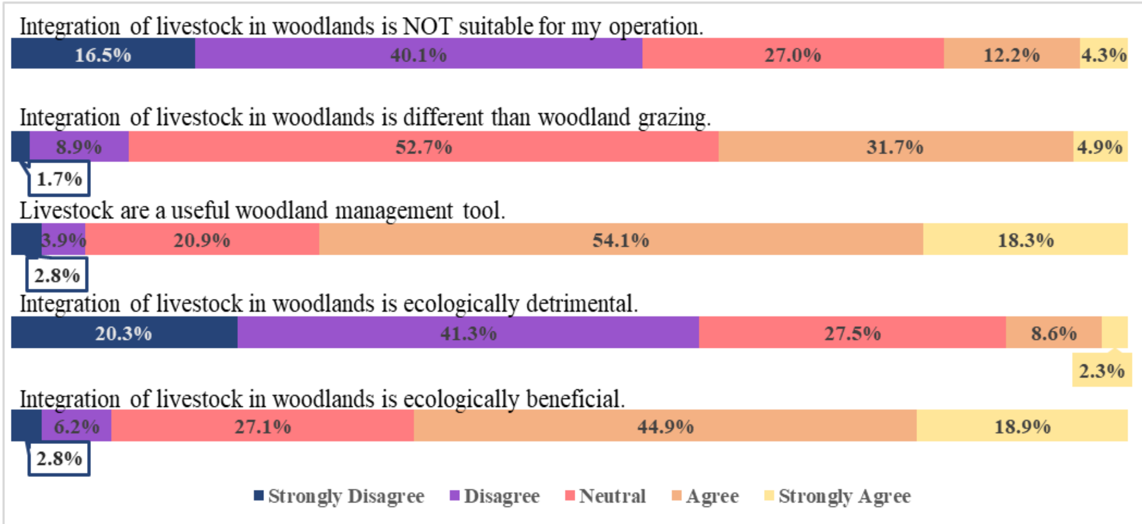

Figure 3.3 Frequency of respondents' (*n* = 347) agreement or disagreement with the perception of woodland silvopasture among Missouri producers. Percent frequencies were reported through descriptive statistics to visually represent the agreement or disagreement with the Likert-items of 87% of respondents.

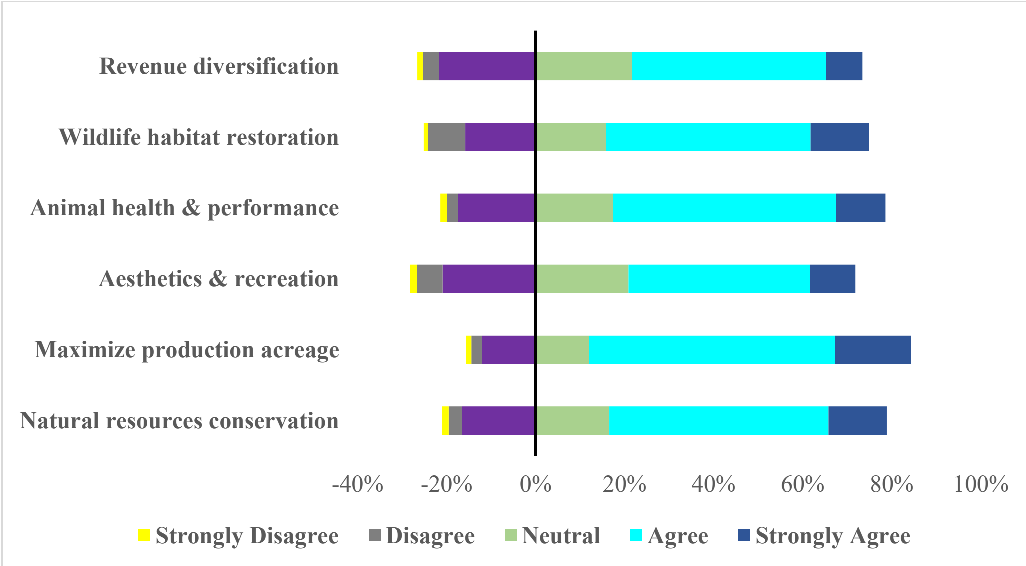

Figure 3.4 Frequency of respondents' (*n* = 328) agreement or disagreement with the perceived benefits of woodland silvopasture among Missouri producers. Percent frequencies were reported through descriptive statistics to visually represent the agreement or disagreement with the Likert-items of 82% of respondents.

Table 3.4 Frequency of respondents that indicated priority to perceived benefits of woodland silvopasture among Missouri producers. Percent frequencies were reported through descriptive statistics to visually represent the agreement or disagreement to the Likert-items of 79% of respondents. An asterisk * indicates the mode among the respondents.

Opportunity of Woodand Silvopasture	*N*	Low Priority	Somewhat Priority	Neutral	Moderate Priority	Essential Priority
	Environmental Benefits (%)					
Improve soil health	326	3.4	8.3	17.2	43.9*	27.3
Management of invasive species	326	2.5	5.8	10.7	40.2	40.8*
Forest health management	322	2.8	7.45	19.9	45.3*	24.5
Establish wildlife habitats	326	5.8	11.9	23.0	38.9*	20.3
	Economic Benefits (%)					
Increase short-term return	320	8.8	10.0	30.3	38.4*	12.5
Revenue diversification	321	5.6	10.9	33.9	37.4*	12.1
Increased land value (NPV)	324	5.9	6.8	25.0	40.4*	21.9
	Social Benefits (%)					
Aesthetics of farm and/or land	317	6.9	10.1	28.7	40.7*	13.6
Recreational services	322	18.0	9.9	39.8*	25.5	6.8
Intergenerational stewardship	318	5.7	9.8	28.6	37.1*	18.9
Social responsibility	319	10.7	8.2	34.8*	32.6	13.8
	Production Benefits (%)					
Improve timber value	324	7.4	11.4	19.8	48.2*	13.3
Reduce seasonal environmental stress for livestock	326	2.5	4.0	15.3	47.6*	30.7
Diversify forage production	323	4.3	6.2	22.9	45.8*	20.7
Increase pasture management	323	3.1	5.9	16.1	41.2*	33.8

Table 3.5 Respondents agreement or disagreement to establishment and management barriers of woodland silvopasture. Percent frequencies were reported through descriptive statistics to visually represent the agreement or disagreement to the Likert-items of 76% of respondents. An asterisk * indicates the mode among the respondents.

Barriers of Woodland Silvopasture	*N*	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	Establishment Barriers (%)					
Conservation program restrictions	310	6.1	10.7	53.6*	23.0	6.8
Financial investment	310	1.3	8.1	40.0	41.9*	8.7
Required thinning of forest	307	2.6	16.0	35.5	40.1*	5.9
Land ownership and/or tenure	307	3.6	11.7	47.8*	28.7	8.1
Limited knowledge of systems	309	1.6	6.5	43.0*	38.5	11.3
	Management Barriers (%)					
Required forest management	308	3.6	12.7	41.2*	37.0	5.5
Minimal animal experience	308	13.6	25.7	41.9*	16.2	2.6
Resource availability	306	2.9	11.1	44.8*	33.0	8.2
Labor/time management	309	2.6	8.7	31.7	44.7*	12.3
Market access for saleable products	307	3.3	11.4	45.6*	32.3	7.5

Table 3.6 Categorical and continuous variables of respondents' current practices and management that influenced the willingness to adopt woodland silvopasture.

Parameter	*P*-value	Odds Ratio	Confidence Interval
Livestock Management Variables			
Pasture and woodlands rotational grazing	0.01	2.46	(1.48, 4.08)
Confined feeding	0.04	1.78	(1.01, 3.15)
Byproducts (distillers)	0.03	2.35	(1.06, 5.17)
Woodland/Forest Management Variables			
Moderately wooded	0.01	2.99	(1.52, 5.92)
Thickly wooded	0.01	2.66	(1.32, 5.37)
Non-commercial thinning	0.01	2.21	(1.16, 4.22)
Mechanical/physical clearing of brush	0.01	2.80	(1.55, 5.05)
Producer Experience			
Forest management experience (15-24 years)	0.03	4.44	(1.15, 17.19)
Silvopasture experience (current or previous)	0.01	1.92	(1.41, 2.61)

Table 3.7 Perceptions, attitudes, and barriers Likert-item variables that influenced respondents' willingness to adopt woodland silvopasture.

Parameter	*P*-value	Odds Ratio	Confidence Interval
Perception of Woodland Silvopasture			
Integration of livestock in woodlands is ecologically beneficial	0.01	1.84	(1.22, 2.79)
Livestock are a useful woodland management tool	0.07	1.46	(0.97, 2.18)
Integration of livestock in woodlands is NOT suitable for my operation	0.01	0.51	(0.38, 0.70)
Perception of Woodland Silvopasture Benefits			
Maximize production acreage	0.01	2.15	(1.23, 3.77)
Animal health & performance	0.02	1.92	(1.11, 3.32)
Wildlife habitat restoration	0.01	1.71	(1.11, 2.62)
Establish wildlife habitats	0.06	1.43	(0.98, 2.10)
Prioritization of Opportunities for Benefits of Woodland Silvopasture			
Forest health management	0.02	1.74	(1.10, 2.80)
Recreation services	0.05	0.67	(0.45, 1.00)
Increase pasture management	0.02	1.96	(1.10, 3.5)
Perceived Barriers to Adoption of Woodland Silvopasture			
Minimal animal experience	0.01	0.69	(0.5, 0.91)
Environmental impact	0.01	1.71	(1.17, 2.50)
Feasibility of establishment	0.03	1.58	(1.05, 2.39)
Lack of interests in woodland silvopasture	0.01	0.38	(0.26, 0.56)
Technical assistance/informational trainings	0.01	2.26	(1.51, 3.38)

Table 3.8 Adoption variables that influenced respondents' willingness to implement woodland silvopasture.

Parameter	*P*-value	Odds Ratio	Confidence Interval
Silvopasture Management Variables			
Environmental impact	0.01	1.71	(1.17, 2.50)
Feasibility of establishment	0.03	1.58	(1.05, 2.39)
Lack of interests in woodland silvopasture	0.01	0.38	(0.26, 0.56)
Technical assistance/informational trainings	0.01	2.26	(1.51, 3.38)

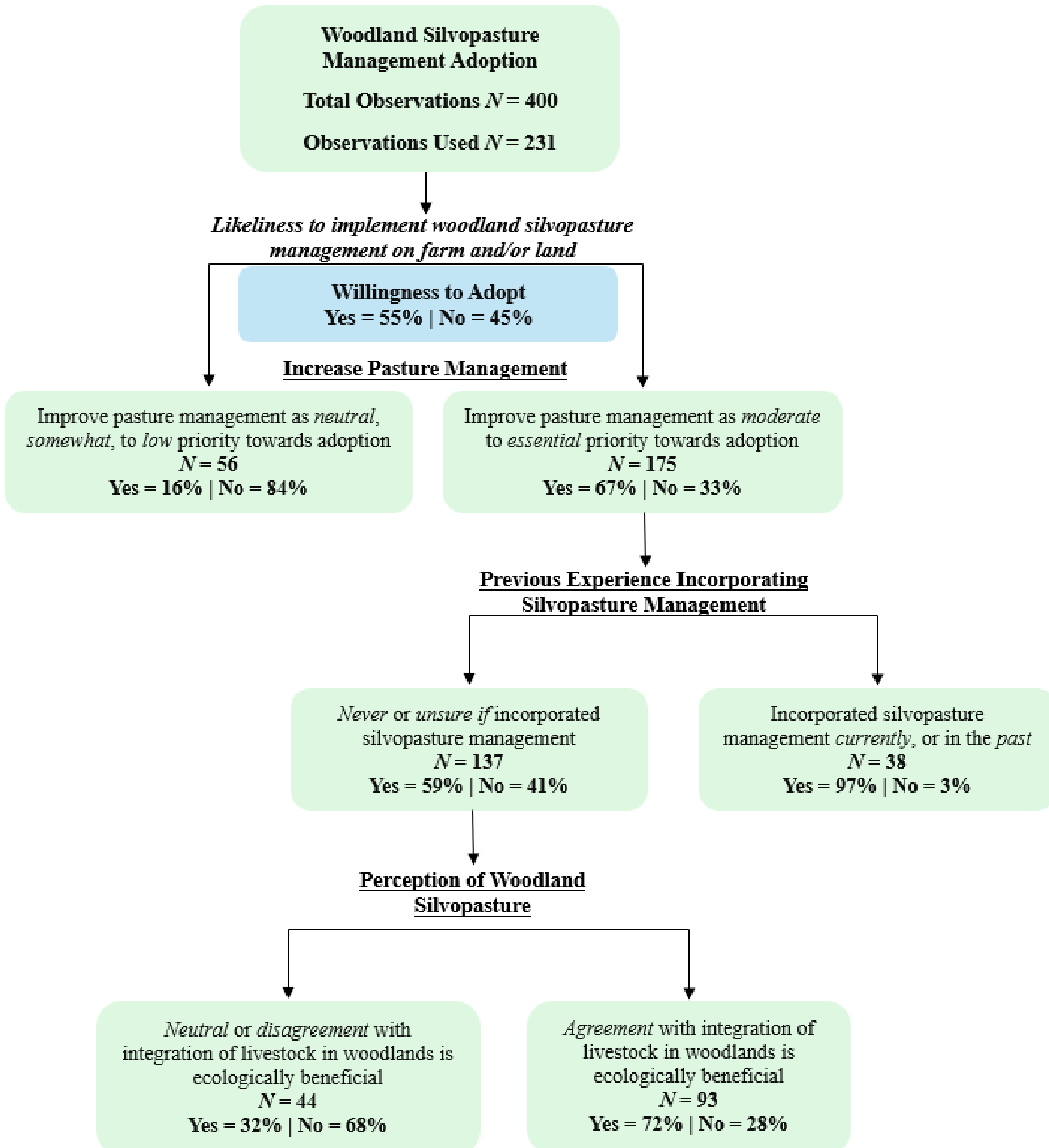

Figure 3.5 Visual diagram representing decision tree model probability of respondents' (n = 231) for indicating profile of the willingness to implement woodland silvopasture.

Chapter IV: Utilizing Goats to Manage Sericea Lespedeza (*Lespedeza cuneata*) for Restoration of Native Warm Season Grass Pastures

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Abstract

Restoration of native prairies and pastures has been prevalent within the Midwest region, including Missouri. The presence of the invasive species sericea lespedeza (*Lespedeza cuneata*), a non-native perennial legume, has hindered this progress by adversely impacting native plant species and evading common control and management strategies. Sericea lespedeza also contains condensed tannins that decrease palatability and nutrient digestibility in large ruminants. Goats and sheep have demonstrated the ability to tolerate condensed tannins, while benefiting from parasite control and animal performance, suggesting small ruminants may be a feasible method to control sericea lespedeza for potential native warm season pasture restoration. During late June 2021, this study began assessing the impact of goat grazing on plant composition within native warm season pastures infested with sericea lespedeza. This study also aimed at evaluating the effect of grazing sericea lespedeza on gastrointestinal parasite presence within goats. Goats were randomly assigned to replicate treatments of high, medium, and low stocking densities applied to pastures containing sericea lespedeza. June – July 2024, three years post-grazing, a subsequent evaluation was conducted of rotational plots grazed at various stocking densities for plant composition and forage nutritive value. Additionally, forage samples were collected to assess nutritive value and condensed tannins. There were no significant differences in fecal egg counts between grazing treatments ($P = 0.26$). Also, there was no observed interaction between grazing treatment and subsequent years following grazing on abundance of sericea lespedeza or other vegetation groups ($P = 0.24$). There were differences in the abundance of warm-season grasses, grass-like species, and forbs in years following the initial grazing season ($P < 0.0001$). Warm season grasses increased in abundance from 11.8 to 36.1% (± 0.11) following the initial grazing period, and grass-like species and forbs were found to decrease from 19.7 to 0.78% (± 0.04) and 17.8 to 9.5% (± 0.02) respectively. Grazing treatments did not significantly impact fecal egg count ($P = 0.26$) or plant species abundance ($P = 0.24$), with sericea lespedeza abundance ranging

between 24-29% (± 0.11). There were descriptive differences observed with fecal egg count and plant species abundance over years following the initial grazing period that suggest goat grazing can be effective with consecutive grazing seasons.

Introduction

Amid the 19th century, native savanna and prairie landscapes in North America dramatically changed with the introduction of non-native plant and animal species for agricultural practices. This included sericea lespedeza (*Lespedeza cuneata*), a non-native perennial warm-season legume introduced to the United States from eastern Asia, now widespread within agricultural settings (Pieters, 1939; Hoveland & Donnelly, 1985; Eddy et al., 2003; Cummings et al., 2007). Originally, sericea lespedeza was introduced to the United States to provide protective cover for sites with poor soils and to control erosion. Sericea lespedeza was further promoted by land management agencies and extension specialists because of its potential as a forage crop, wildlife cover and food, and seed production (Pieters, 1939; Davison, 1945; Guernsey, 1970; Eddy et al., 2003; Cummings et al., 2007; Ohlenbusch et al., 2007; Middendorf et al., 2008).

Sericea lespedeza flourishes in deep, fertile, and well-drained soils, and possesses a deep taproot that facilitates its ability to tolerate drought conditions and persist in acidic and marginally fertile soils (Hoveland & Donnelly, 1985; Ohlenbusch et al., 2007). It is resistant to various insects and diseases and can produce an abundance of seeds (Pieters, 1939; Guernsey, 1970; Hoveland & Donnelly, 1985; Davidson, n.d.). Moreover, sericea lespedeza contains allelopathic chemicals that can affect surrounding plants, allowing it to outcompete native and other introduced plants for resources (i.e., water, nutrients). These allelochemicals affect nearby plants by reducing seed germination, diminishing plant growth, and decreasing biodiversity (i.e., abundance, species richness) (Kalburtji & Mosjidis, 1992; Eddy & Moore, 1998; Dudley & Fick, 2003; Coykendall, 2011; Ogden et al., 2019; Davidson, n.d.). Thought to be beneficial for land management and production, these characteristics of sericea lespedeza have become an invasive nuisance, counteracting perceived benefits.

Other instances of conflicting previously perceived benefits are with wildlife (mainly birds such as quail) that have been shown to forage on sericea lespedeza seeds, although the seeds are undigestible and deficient in protein requirement necessary for survival (Kilgore et al., 1998; Ohlenbusch et al., 2007). Within pastures, sericea lespedeza has the capacity to displace desirable forage, reduce forage biomass, diminish the efficiency of cattle grazing, and cause the overgrazing of surrounding plants. Tracy et al. (2022) reported throughout the grazing season the percent cover and amount of biomass of sericea lespedeza increased, though it had limited impact on animal performance and steers tended to avoid the legume species. This is because it contains condensed tannins that bind to the proteins within the plant, which make it unpalatable, reduces digestibility, and negatively impacts cattle performance (Henson et al., 1943; Addisu, 2016; Tracy et al., 2022).

Due to the plant's characteristics of adaptability in a variety of conditions, competitiveness with native plant species, and resistance to control and management strategies, sericea lespedeza has expanded nationwide to become invasive in many ecosystems (i.e., native prairies, grasslands, shrublands, forests, introduced pastures) (Eddy & Moore, 1998; Dudley & Fick, 2003; Ohlenbusch et al., 2007; Middendorf et al., 2008). Although sericea lespedeza presence has expanded across the United States, it primarily impacts ecosystems throughout the Midwest and Great Plains by seed harvest and plantings, movement of hay production, and grazing animals (Eddy et al., 2003; Silliman & Maccarone, 2005; Ohlenbusch et al., 2007; Middendorf et al., 2008). Control and management of sericea lespedeza within the central United States, specifically, has become a priority to counteract adverse impacts on vegetation composition, native ecosystems, wildlife species, and cattle grazing (Eddy & Moore, 1998; Eddy et al., 2003; Fitzgerald et al., 2004; Stanley et al., 2008; Rowe, 2010; Smith, 2014; Trowbridge et al., 2016).

Methods of control and management for sericea lespedeza have included mechanical removal, prescribed fire, chemical application, and biological interventions (Poos & Hetrick, 1945; Brock, 1968; Buntin, 1991; Fitzgerald et al., 2004; Bradley & Masters, 2007; Rook et al., 2011; Trowbridge et al., 2016; Lemmon, 2021). Mechanical removal by mowing has shown to be variable and inadequate in managing the plant's abundance. Prescribed spring fire enhances seed germination and exacerbates growth productivity (Gucker, 2010; Wong et al., 2012; Jordan et al., 2022). Chemical control using herbicides is common as a viable control method, though can be variable, expensive, ineffective in the long-term, and can destroy native legumes and other broad-leaved plants within the vicinity (Eddy et al., 2003; Farris & Murray, 2009). Biological interventions also have been observed with invertebrates such as three-cornered alfalfa hopper (Spissistilus festius), grasshopper (Schistocerca americana), and lespedeza webworm (Tetralopha scortealis) in elimination of seed production and defoliation of the species (Poos & Hetrick, 1945; Buntin, 1991; Eddy et al., 2003).

More recently, researchers have investigated integrative approaches utilizing ruminants for grazing management to control sericea lespedeza (Lemmon et al., 2017; Ogden et al., 2019). Lemmon et al. (2017) reported no significance in steer body weight or average daily gain ($P \geq 0.59$) indicating grazing sericea lespedeza did not negatively impact growth performance. This study also reported greater preference ($P < 0.01$) for sericea lespedeza among sheep following steer grazing impacting vegetation composition. Grazing management for control of sericea lespedeza with small ruminants (i.e., sheep, goats) is preferred due to the tolerance of condensed tannins within the plant compared to cattle (Lemmon et al., 2017). Sericea lespedeza contains condensed tannins (CT), plant secondary metabolites, shown to negatively impact the digestibility and palatability in large ruminants; yet these properties provide beneficial factors for small ruminants to influence parasite control and animal performance (Min & Hart, 2003; Shaik et al., 2006; Terrill et al., 2007; Burke et al., 2012; Mechineni et al., 2014; Addisu, 2016; Mahachi et al., 2020). Mechineni et al. (2014) showed a 95% decrease in fecal egg count (FEC) and adult nematodes ($P < 0.05$) in goats during autumn grazing of sericea lespedeza. Similar parasitic control was reported among lambs to manage gastrointestinal nematodes (GIN) with grazing of sericea lespedeza in later summer (Burke et al., 2012). The capacity of small ruminants to advantageously utilize sericea lespedeza as a parasitic control agent and vegetation source facilitates the potential for small ruminant grazing to aid in management.

Missouri's native and agricultural landscapes, like other states within the Midwest, have been impacted by the aggressive expansion of sericea lespedeza (Gucker, 2010). Missouri's Ozark Region specifically has been threatened with the presence of the invasive plant, prominent within pastures and woodlands. Thus, the management and control of sericea lespedeza within the region's landscapes, especially among native warm season grasses, can offer the opportunity towards restoration of native landscapes (i.e., prairies, savannas, and woodlands), establishment of sustainable grazing systems, and diversified income for producers. Goats have demonstrated the ability to act as a biological agent to control invasive species, though minimal research has been conducted for controlling sericea lespedeza (Brock, 1968; Hart, 2021). To determine the potential for goat grazing as a management tool, the project aims to (1) assess the impact of grazing intensity on relative abundance of native warm season grasses infested with sericea lespedeza and (2) evaluate the effect of grazing sericea lespedeza on gastrointestinal parasite presence within goats.

Materials and Methods

Animal experimental procedures were approved by the University of Missouri Animal Care and Use Committee and adhered to procedures outlined in the Animal Care and Use Protocol (9988).

Study Site and Experimental Design

A multi-year grazing project (2021-2024) was established in the summer of 2021 at the Land of the Osages Research Farm (LORF), a University of Missouri Agricultural Experiment Station (AES) situated within the Ozark Region, in Gravois Mills, Missouri. This farm consists of 223-hectares of mixed forests (190.2 ha), and open pasture ground (32.4 ha) historically used for conventional farming and grazing practices. Within the farm, three 2.43-hectare open pastures containing sericea lespedeza in various densities were designated as study sites. Each pasture was designated as a block grazing unit and was sub-divided into three grazing treatments (50 m x 100 m each) for a randomized complete block design. Each grazing unit was further subdivided into four 50 m x 25 m paddocks to achieve increased stocking density. Grazing plots were identified as experimental units, replicated, with each plot randomly assigned one of three levels of rotational grazing treatments. Grazing treatments included High (14-head), Medium (7-head), and Low (4-head) stocking densities. Stocking densities achieved within each treatment paddock were as follows: High (14-head / 0.12 ha = 116 head/ha); Medium (7-head / 0/12 ha = 58 head/ha); Low (4-head / 0.12 ha = 33 head/ha).

Mixed breed goats (n = 75) of various sexes and ages with an average weight of 24.4 kg were acquired from a local sale barn for the grazing season (July - October 2021). Goats were randomly assigned to either High, Medium, or Low stocking treatments within each block. Goats were grazed within these rotational treatments for the initial year (2021) and sold at the end of the grazing season (October 2021). During the grazing season goats were provided with water via 15-gallon water tanks, transported to each paddock. Goats were ad libitum access to a mineral block.

Following Year 1 (2021) of grazing, the pastures were managed by haying in Year 2 (2022) and Year 3 (2023) post grazing.

Animal and Grazing Measurements

Between late July – mid October 2021 (July 21st – October 20th) goats were grazed within plots at high, medium, and low stocking for a total of 13 weeks. Animal FAMACHA scores were collected prior to grazing (Year 1) to determine baseline health. This was completed by using the FAMACHA scoring card (eye color chart) on a scale of 1-5, to detect anemia in goats using the mucous membrane around the eyes (Kaplan et al., 2004). An average FAMACHA score of 1.9 indicated goats in the study were non-anemic. To evaluate the effect of grazing sericea lespedeza on gastrointestinal parasite control in goats, fecal egg counts (FEC) were collected per animal within each treatment group. Pre- and post- grazing fecal egg counts (FECs) were obtained by collecting feces of goats within each treatment and shipping samples to Texas A&M AgriLife, Stephenville, TX to determine the number of worm eggs excreted per gram of feces (EPG). These counts were used to estimate the amount of gastrointestinal parasite concentration change throughout the goats grazing period of sericea lespedeza.

Plant Species Abundance and Nutrient Value Measurements

Prior to grazing in Year 1 (late June 2021), pasture plant community compositions were recorded, with a focus on sericea lespedeza. Plant abundance was sampled using a line-point intersect method along a 23-meter transect with knots tied every 0.30 meters (Coulloudon et al., 1999). Within each pasture (at block-level), vegetation was recorded at 38 intercepts (points) at 0.61-meter interval along 16 transects. Vegetation was sampled by plant group, including sericea lespedeza (SL), cool season grasses (CSG), warm season grasses (WSG), other forb species (OF), grass-like species (GL), shrubs (S), and trees (T). The presence of the species group was recorded at each point where a plant within the species group crossed directly below or above the line.

In June 2022 and June 2024, the line-point intersect method was used for repeated plant community measurements. This method was modified to sample vegetation along four transects (2022) and two transects (2024) within subdivided grazing treatment plots. Relative abundance of each plant group was calculated as the number of occurrences of each group divided by the total number of samples recorded within each plot. In June 2024, forage was collected to assess biomass production, forage nutritive value, and condensed tannins within the pastures. Forage was destructively sampled within one 1m x 1m quadrat per subplot within each treatment. Representative forage samples were collected among pastures and composited to estimate the animal diet during grazing throughout the fields (Goosey et al., 2022). Forage samples were stored in a freezer until prepared for biomass and forage nutritive analysis.

To estimate biomass production, fresh samples were weighed using a balance scale (A&D Engineering, Model EK-30KL balance, Ann Arbor, MI, USA) at the Horticulture and Agroforestry Research Farm (HARF) in New Franklin, MO. Samples were then dried in a forced air-flow oven (Blue M Electric, POM-1406F, Watertown, WI, USA) at 55°C for 72 hours. Post drying, samples were weighed to record dry weight and calculate percent dry matter (DM). Dried samples were ground through a 1 mm particle size screen with a laboratory cutting mill (Thomas Scientific, Thomas-Wiley Model 4 mill, Chadds Ford Township, PA, USA) and stored in sampling bags to prepare for subsequent analysis. Samples were analyzed for nutritive value (i.e., lab dry matter (DM), organic matter (OM), neutral detergent (NDF), and acid detergent fiber (ADF) by the ruminant nutrition and forage physiology lab protocols in the Animal Science Research Center at the University of Missouri.

Each forage analysis was conducted in duplicate to produce accurate data output. For lab DM analysis, aluminum weighing pans were marked to indicate two pans per forage sample.

Empty aluminum weighing pans were recorded and then weighed on a balanced scale (Fisher Scientific, Accu-124 precision balance, Hampton, NH, USA). Weight of the empty aluminum pan was recorded, then tared to weigh dried forage samples. The samples were weighed within the pans to approximately 1.0000 grams and recorded. Aluminum pans with forage samples were removed and gently shaken to uniformly distribute forage to ensure even and adequate drying. Each aluminum weighing pan was then placed on a metal tray for drying. This process was repeated for the remaining forage samples. Forage samples were then moved into a general-purpose oven (Fisher Scientific, Model 6925 isotemp oven, Hampton, NH, USA) to dry at 105℃ for 24 hours. Once 24 hours had lapsed, samples were removed and transferred to a desiccator to allow samples to cool to room temperature. Cooled samples were then weighed on a tared balance and weight was recorded. Lab DM % was then calculated by:

$$\text{Lab DM (\%)} = \frac{105℃\ DM\ weight}{60℃\ DM\ weight} \text{x } 100$$

Organic Matter (OM) was analyzed by moving DM samples into a muffle furnace (Thermo Fisher Scientific, Lindberg/BlueM 5.3L B2 Moldatherm muffle furnace, Waltham, MA, USA) for ashing at 600℃ for six hours. The oven was allowed to cool to below 200℃. Then samples were removed, transferred to a desiccator for cooling, and weighed to 0.0001g. Ash and OM % were calculated by:

$$\text{Ash (\%)} = \frac{ash\ weight}{100℃\ DM\ weight} \text{x } 100$$

$$\text{OM (\%)} = (100 - \text{ash \%})$$

Fiber analysis was conducted using methodology developed from Van Soest et al. (1991). Analysis for neutral detergent fiber (NDF) started by labeling filter bags (Ankom Technology, F57 filter bag, Macedon, NY, USA) with a solvent-resistant marker. Each empty filter bag was then weighed, recorded, and tared on a balance. Forage samples were placed into empty bags to weight of 0.45 – 0.50 g and heat sealed to ensure complete closure. An empty bag was labeled and weighed to include in analysis to determine the blank bag correction. Filter bags were fitted within Bag Suspender Trays and then placed into a fiber analyzer (Ankom Technology, A200 fiber analyzer, Macedon, NY, USA) and washed with a mild detergent made up of 80-100℃ distilled water and acetone. After rinsing, the filter bags were air dried overnight to allow evaporation of acetone and then placed in 100℃ oven for 2-4 hours. Sample bags were weighed, recorded, and used to calculate NDF %:

$$\text{NDF (\%)} = \frac{(washed\ bag\ weight)}{initial\ bag\ weight} \text{ x } 100$$

Samples bags were then sequentially used for acid detergent fiber (ADF) analysis by following similar equipment and drying procedures conducted for ADF with use of a stronger sulfuric acid. Sample bags were washed, dried, and weighed as previously mentioned and calculated by:

$$\text{ADF (\%)} = \frac{(washed\ bag\ weight)}{post{-}NDF\ bag\ weight} \text{ x } 100$$

Both NDF and ADF were adjusted using alfalfa standards that were included in every run. Samples (0.5-1.0 lbs.) were sent to Texas A&M AgriLife, Stephensville, TX for crude protein analysis. Samples were analyzed via Dumas combustion measurement (Shea & Watts, 1939). Chemical analysis of condensed tannins were also measured to develop a nutrient profile (Naumann et al., 2014).

Statistical Analysis

Animal measurements, relative abundance of vegetation by plant group, and forage data collected June 2021 – 2024 were organized and statistically analyzed through the statistical analysis software (SAS) 9.4. Descriptive statistics were used to characterize animal measurements and plant community composition. Averages were calculated for fecal egg counts.

Abundance was determined as the frequency of occurrence along transect with 38 sampling points. The frequency of occurrence was the proportion of those points at which the plant functional group was present. Plant community frequency was used to calculate plant species composition by totaling the frequency counts per plant function group and averaging by the total count for all plant species. Percent species compositions were then compared among block grazing unit, treatment, and across treatment year.

Generalized linear mixed models (GLMM) were used to determine the effect of grazing sericea lespedeza at various stocking treatments (High, Medium, Low) on animal fecal egg count, plant composition, and forage nutrient analysis. Each model included the fixed effect of stocking rate and random effect of block. Animal fecal egg count response was analyzed by including the main effect of stocking rates with condensed tannins as a covariate. The GLMM model for plant composition incorporated repeated measures of the relative abundance of vegetation plant groups, including sericea lespedeza (SL), cool season grasses (CSG), warm season grasses (WSG), other forb species (OF), grass-like species (GL), shrubs (S), and trees (T), with year as a fixed effect. Relative abundance of shrubs and tree cover classes was zero and thus was not modeled. GLMM was also used to estimate the significance of goat grazing with different stocking rates on forage nutrient analysis (i.e., lab dry matter, organic matter, nitrogen detergent fiber, acid detergent fiber, crude protein, condensed tannins).

Results

Animal Fecal Count Measurements

There was no effect of grazing treatment on the average beginning ($P = 0.61$) and ending ($P = 0.39$) fecal egg count (FEC) (Table 4.1). There was no effect of grazing treatment on difference of FEC (*P* = 0.66) or percent change (*P* = 0.26). Fecal egg count was also not affected by covariate condensed tannins (CT) (*P* = 0.25).

Plant Community Composition

There was no observed interaction between grazing treatment and year (*P* = 0.24) (Figure 4.1), no effect of grazing treatment (*P* = 0.38) (Table 4.2), and no effect of year (*P* = 0.19) (Table 4.3) on relative abundance of sericea lespedeza (SL). The relative abundance of SL was numerically higher than Low grazing stocking rate (29 ± 0.11%) compared to Medium (28 ± 0.11%) and High (24 ± 0.11%) stocking rate (Table 4.3). In 2022 (31 ± 0.11%) SL presented with a numerically higher relative abundance compared to 2021 (25 ± 0.11%) and 2024 (26 ± 0.11%) (Table 4.2).

There was no interaction between grazing treatment and year (*P* = 0.97) (Figure 4.1), no effect of grazing treatment (*P* = 0.83) (Table 4.2), and no effect of year (*P* = 0.61) (Table 4.3) on relative abundance of cool-season grasses (CSG). The CSG abundance was numerically higher for Low stocking rate (27 ± 0.04%) compared to Medium (26 ± 0.04%) and High (24 ± 0.04%) stocking rates (Table 4.2). The CSG abundance was also numerically higher in 2024 (28 ± 0.04%) compared to 2021 (27 ± 0.04%) and 2024 (23 ± 0.04%) (Table 4.3).

There was no interaction between grazing treatment and year (*P* = 0.7) (Figure 4.1), or effect of grazing treatment (*P* = 0.24) (Table 4.2) on relative abundance of warm-season grasses (WSG). Year had a significant effect on relative abundance of WSG (*P* < 0.0001) (Table 4.3), with significant increases in WSG in each year (Table 4.3). Overall, WSG numerically tended to be more abundant within the High stocking rate compared to Medium and Low, and across subsequent years following initial grazing (Figure 4.3).

There was no observed interaction between grazing treatment and year (*P* = 0.93) (Figure 4.1), or no effect of grazing treatment (*P* = 0.84) (Table 4.2) on the relative abundance of grass-like (GL) vegetation. Year was significant in affecting the relative abundance of GL ($P < 0.0001$) (Table 4.3). This was significantly different between 2021 (20 ± 0.03%) and 2022 (11± 0.03%) ($P < 0.01$), 2021 and 2024 (0.7 ± 0.03%) ($P < 0.0001$), and 2022 and 2024 ($P < 0.003$). GL reported a decrease in abundance among treatments and years following initial grazing, with abundance in Year 2 post-grazing consistently below 1% (Figure 4.4).

There was no observed interaction between treatment and year effects ($P = 0.40$) (Figure 4.1), or main effect of grazing treatment ($P = 0.91$) (Table 4.2) on the relative abundance of other forbs (OF) ($P = 0.40$). Year was significant in affecting the relative abundance of OF ($P < 0.001$) (Table 4.3). Other forbs were most abundant in 2021 (18 ± 0.02%), and decreased in 2022 (8.4 ± 0.02%), and 2024 (9.5 ± 0.02%) (Table 4.3).

Nutrient Value Measurements

There was no treatment effect observed on forage nutritive values for lab dry matter ($P = 0.90$), nitrogen detergent fiber ($P = 0.85$), acid detergent fiber ($P = 0.78$), crude protein ($P = 0.92$), and condensed tannins ($P = 0.44$) (Table 4.4). Grazing treatment was significant in affecting organic matter ($P = 0.008$) (Table 4.4). Both Low and Medium stocking densities were 94.0% and 94.6%, but High stocking was lower (93.1%) when compared to both. Condensed tannins were not different ($P = 0.44$) among grazing treatments, ranging from 5.66 mg/g in high treatment down to 1.65 mg/g in medium treatment (Table 4.4).

Discussion

Animal Fecal Count Measurements

Grazing studies have reported reductions in fecal egg counts among goats grazing sericea lespedeza (Min & Hart, 2003; Min et al., 2005; Burket et al., 2012; Mechineni et al., 2014). Mechineni et al. (2014) reported a 95% reduction in fecal egg counts among fall-grazing goats consuming sericea lespedeza exclusively, compared to goats grazing a mixture of sericea lespedeza and Bermudagrass (*Cynodon dactylon*) (71%) and to a control that was predominately Bermudagrass. This difference was also explained by the condensed tannins content found in the plant, with higher levels indicated in the leaves (16.0g/100g) versus the stems (3.3g/100g) (Mechineni et al., 2014). This study also reported a whole plant condensed tannin level content of 12.5g/100g, which is three times higher than the average content found within our study. Grazing the combination of sericea lespedeza and perennial warm season grasses also showed an initial delay in lowering fecal egg count compared to grazing sericea lespedeza exclusively (Mechineni et al., 2014). This was attributed to the goat's initial preference for Bermudagrass, followed by later consumption of sericea lespedeza. A study with early summer grazing of Angora females and kids showed a 78% reduction of FEC following grazing of sericea lespedeza (Min et al., 2005). This study reported lower FEC in females grazing SL (145 eggs/g) compared to rotational grazing of SL and control forage (ROT) (329 eggs/g), and significantly lower than grazing crabgrass (*Digitaria ischaemum*)/Kentucky 31 tall fescue (*Festuca arundinacea*) control forage (CTF) (894 eggs/g). Such FEC reduction was also reported in kids grazing SL (550 eggs/g) compared to ROT (2757 eggs/g), and CTF (3600 eggs/g) (Min et al., 2005). This study also reported grazing sericea lespedeza lowered the total fecal egg count output and larval development (Min et al., 2005). Moreover, grazing of sericea lespedeza was observed to enhance immune response within goats. Similar reports of reduced gastrointestinal nematode presence were noted in grazing lambs in late summer (Burke et al., 2012).

Our study did not observe an impact on FEC likely due to considerably lower SL condensed tannin content within treatment, High (5.7g), Medium (1.7g), and Low (3.5g), compared to other studies. Condensed tannin content of SL is shown to peak during late summer – early fall (Eckerle et al., 2010; Preedy et al., 2013), which could explain the low content levels and lack differences in FEC among treatments in our other study compared to other studies. The abundance of SL within our pastures was similar to cool-season grasses (CSG) throughout the study, and warm-season grasses (WSG) following the initial grazing period. This suggests goats in this study grazed within pastures with greater plant diversity than those of other studies from mid-summer to mid-October. Though goats grazed within the condensed tannin peak period, SL abundance among other vegetation could have impacted goats not selecting SL as prevalent as in other studies. This means SL could have become a secondary or tertiary forage source as results showed a significant increase of WSG and decrease of grass-like species (GL) and other forbs (OF). Condensed tannin levels also could have been diluted by other vegetation impacting nutrient availability and increasing competition, thus reducing tannin production.

Non-grazing studies have also shown a reduction in fecal egg counts in goats that have consumed stored forms of sericea lespedeza (Shaik et al., 2006; Terrill et al., 2007; Kommuru et al., 2014). Shaik et al. (2006) reported an 88% FEC reduction in goats fed sericea lespedeza hay compared to bermudagrass hay. Another study also showed a reduction in FEC among goats fed SL hay (88%) (Terrill et al., 2007). Furthermore, this study reported a higher reduction when SL hay was fed in a pelleted form (88%) compared to ground SL hay (54%). A more recent study noted the potential of pelleted sericea lespedeza to control parasites and reduce gastrointestinal nematodes (82%) in weaned goats by the end of feeding period (Kommuru et al., 2014).

Plant Community Composition

Removal of invasive and undesired species by biological interventions has shown practicality in reducing competition and controlling existing weed species. This has included using livestock grazing as a management strategy for prairie restoration, and specifically rotational grazing during different seasons (Menke, 1992; Johnson & Sandercock, 2010; Otfinowski et al., 2017). Jackson (1999) reported native grasses increasing in plots from 1% to 37% within three years following controlled cattle trampling, facilitating establishment and growth of seeded native species. In our study, WSG increased through time following grazing from 11% to 36%. This indicates that goats can have a similar impact on pasture composition in our study compared to others. Studies have also shown grazing combined with other management approaches can affect species richness. Collins et al. (1998) showed that grazing bison independently or post-burning increased the species richness of cool-season (8.3 and 6.6 species/50 m^2, respectively), warm-season (9.4 and 9.9 species/50 m^2, respectively), and forbs (41.5 and 40.8 species/50 m^2, respectively) compared to burning only regimes and control (6.4 and 3.6 species/50 m^2) (6.6 and 8.3 species/50 m^2), and (29.1 and 23.2 species./50 m^2) respectively. Species richness was reported to be the highest when ruminant grazing was combined with burning regimes (Collins et al., 1998). Our study did not collect species richness, though examining other management strategies with and independent of goat grazing to impact species richness is warranted for future study.

Goats have been used as an alternative management strategy for invasive species because their grazing behavior is less restrictive and more opportunistic than larger ruminants (Lu, 1988). Goats are particularly known to consume SL, mainly the leaves of plants, which was observed in our study. This is shown by goats grazing behavior as foragers and preference to eat the leaves of brush and shrub species (Lu, 1988; Luginbuhl, 1995). Though depending on the growing season, goats will be selective for the most palatable forage to consume initially (Luginbuhl, 1995). Technical reports have noted that goats are more likely to graze forbs earlier, between spring and summer, then transition to consuming warm season species (Luginbuhl, 1995; Rice, n.d.). This could explain the differences in our study shown in plant abundance among WSG, G, and OF compared to SL.

A study in the Upper Midwest examined the effectiveness of goat grazing for one week in consecutive years to control SL. This study reported two to three times lower density ($P = 0.003$), 10 times lower biomass ($P = 0.03$), and two times shorter height ($P = 0.001$) compared to ungrazed plots (Klodd et al., 2009). Compared to Klodd et al. (2009), grazing within the present study was extended for nine weeks compared to a shorter grazing period, with no observed differences in grazing densities on SL. This extended grazing period without intermediate measurements of SL could have resulted in not recognizing the impact of goat grazing on SL within the grazing season. Differences were observed in the present study among pasture units in post-grazing years compared to the initial grazing season (Table 4.3). This showed the plant abundance of WSG, GL, and OF were influenced after the first grazing season (Table 4.3). This variation over subsequent years could be impacted by haying following grazing, which decreased competition of WSG compared to other vegetation species over time and pronounced goat selective grazing for GL and OF.

Barnewitz (et al., 2009) showed mowing exclusively reduced SL seed density and seed mass by 90% and 60% respectively, compared to goat grazing and control treatments. This difference is attributed to mowing and removing aboveground biomass compared to goats that selectively graze SL. This study did not observe a difference between grazing rotations at seven consecutive days over two years, though Barnewitz et al. (2009) anticipates observing an effect of goat grazing over time. Like Barnewitz et al. (2009) the present study did not observe a difference of goat grazing densities to impact SL. To further explain these differences future studies could include assessing grazing impact of SL intermediately within grazing period or having additional grazing seasons. Though, years following initial grazing season and consecutive haying showed a numerical trend increasing cool-season grasses (CSG) and significantly increasing WSG and decreasing other forbs (OF). We can infer that consecutive grazing over time could eventually show significant differences within grazing because SL is being selectively impacted versus eliminated. Subsequent haying was used following the initial grazing season per regular management and could justify the impact on WSG, GL, and OF. This warrants further research into combining grazing and other management approaches and comparing this to exclusively haying or burning and grazing with intermediate SL observations.

Conclusion

Goats have the capacity to act as management tools in impacting the abundance of invasive species like sericea lespedeza for potential prairie and pasture restoration. This is because goats can consume sericea lespedeza, using the plant as a forage source and benefit from the condensed tannins anti-parasitic properties impacting fecal egg count. Despite other literature demonstrating a reduction in FEC by ruminants consuming SL, our study did not see a difference, suggesting there is a bioactive threshold to see an effect. Goat stocking density did not affect the relative abundance of sericea lespedeza or other plant-species classes within the pasture. However, the relative abundance of warm-season grasses, grass-like species, and forbs post-grazing changed over the next few years following grazing. This implies goat grazing can affect the abundance of vegetation, though further research is warranted into impact of grazing seasons coupled with additional management and control strategies. Though our study had limitations of the response of fecal egg count and plant abundance, other studies solidify the potential for goat grazing to be included in efforts for prairie and grassland restoration.

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Table 4.1 Fecal egg counts before and after grazing within goats of High (14-head), Medium (7-head), and Low (4-head) stocking rate treatments

Fixed Effects	**High**	**Medium**	**Low**	**P-value**
		Least Square Means (%)		
BFEC[1]	2183.99 ± 547.05	2528.57 ± 547.05	1716.67 ± 547.05	0.61
EFEC[2]	1088.41 ± 242.30	971.11 ± 242.30	1479.17 ± 242.30	0.39
DFEC[3*]	1151.14 ± 702.62	888.89 ± 702.62	219.44 ± 702.62	0.66
PCFEC[4]	647.24 ± 220.68	224.21 ± 220.68	52.29 ± 220.68	0.26

Table 1. [1]Beginning Fecal Egg Count, [2]Ending Fecal Egg Count, [3]Difference Fecal Egg Count, [4]Percent Change Fecal Egg Count.

Table 4.2 High (14-head), Medium (7-head), and Low (4-head) stocking density treatments among relative abundance of vegetation classes.

Fixed Effects	**High**	**Medium**	**Low**	**P-value**
		Least Square Means (%)		
Sericea Lespedeza	24.3 ± 0.11	27.7 ± 0.11	29.4 ± 0.11	0.38
Cool-Season Grasses	24.0 ± 0.04	26.4 ± 0.04	27.2 ± 0.04	0.83
Warm-Season Grasses	28.8 ± 0.11	24.1 ± 0.11	21.2 ± 0.11	0.24
Grass-like	11.5 ± 0.04	10.4 ± 0.04	9.6 ± 0.04	0.84
Other Forbs	11.5 ± 0.02	11.9 ± 0.02	12.4 ± 0.02	0.91

Table 4.3 Vegetation class relative abundance following before (2021) and post (2022 and 2024) goat rotational grazing on native warm season pastures. Means followed by the same lowercase superscript within the columns (year) within each response variable are not different.

Fixed Effects	**Year 2021**	**Year 2022**	**Year 2024**	**P-value**
		Least Square Means (%)		
Sericea Lespedeza	24.7 ± 0.11	31.1 ± 0.11	25.7 ± 0.11	0.19
Cool-Season Grasses	26.5 ± 0.04	22.9 ± 0.04	28.2 ± 0.04	0.61
Warm-Season Grasses	11.3 ± 0.11^{c}	26.7 ± 0.11^{b}	36.1 ± 0.11^{a}	<0.001
Grass-like	19.7 ± 0.04^{a}	11.1 ± 0.04^{b}	0.78 ± 0.04^{c}	<0.001
Other Forbs	17.8 ± 0.02^{a}	8.4 ± 0.02^{c}	9.5 ± 0.02^{b}	<0.001

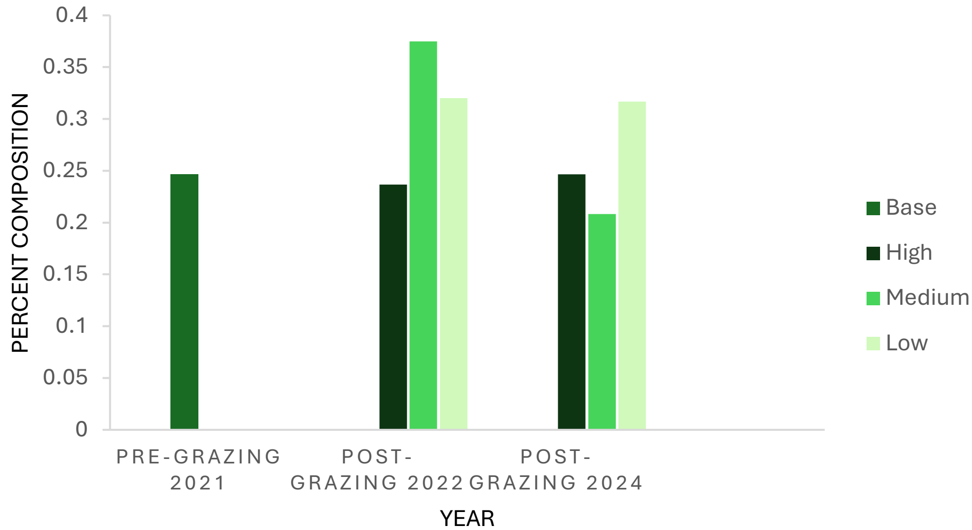

Figure 4.1 Fixed effects interaction (P = 0.24) grazing treatments of High (14-head), Medium (7-head) and Low (4-head) densities and year of pre-grazing 2021 (base), post-grazing 2022, and post-grazing 2024 on relative abundance of sericea lespedeza (*Lespedeza cuneata*). Pre-grazing sampling was not conducted at the experimental unit level and used as an initial comparison for post-grazing years.

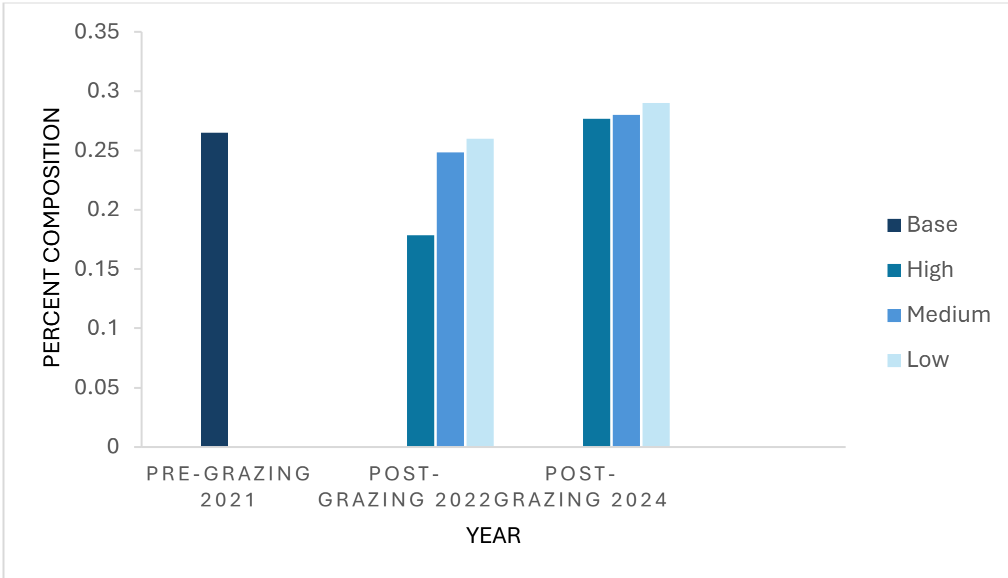

Figure 4.2 Fixed effects interaction (*P* = 0.97) grazing treatments of High (14-head), Medium (7-head) and Low (4-head) densities and year of pre-grazing 2021 (base), post-grazing 2022, and post-grazing 2024 on relative abundance of cool-season grasses. Pre-grazing sampling was not conducted at the experimental unit level and used as an initial comparison for post-grazing years.

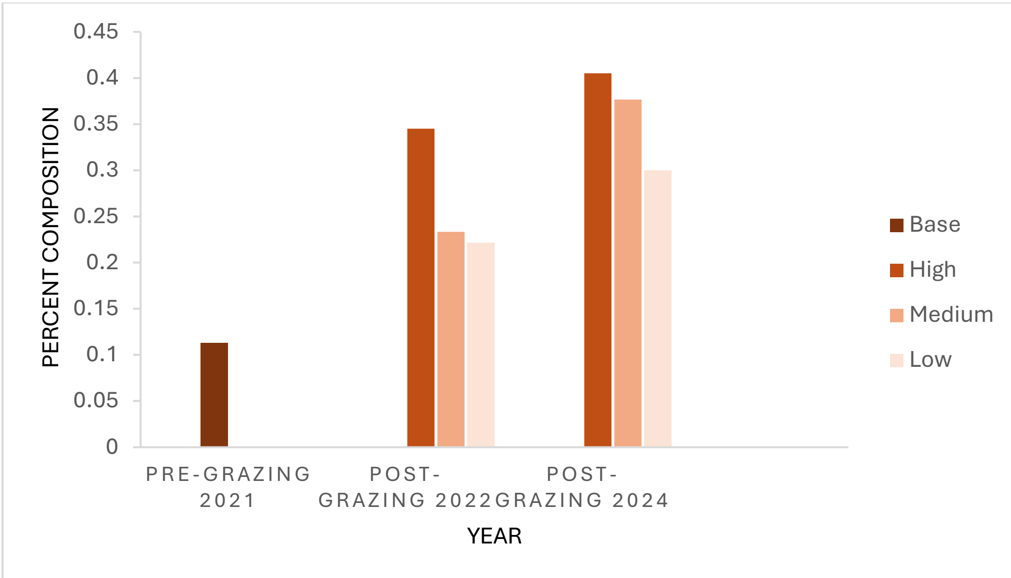

Figure 4.3 Fixed effects interaction ($P = 0.72$) grazing treatments of High (14-head), Medium (7-head) and Low (4-head) densities and year of pre-grazing 2021 (base), post-grazing 2022, and post-grazing 2024 on relative abundance of warm-season grasses. Pre-grazing sampling was not conducted at the experimental unit level and used as an initial comparison for post-grazing years.

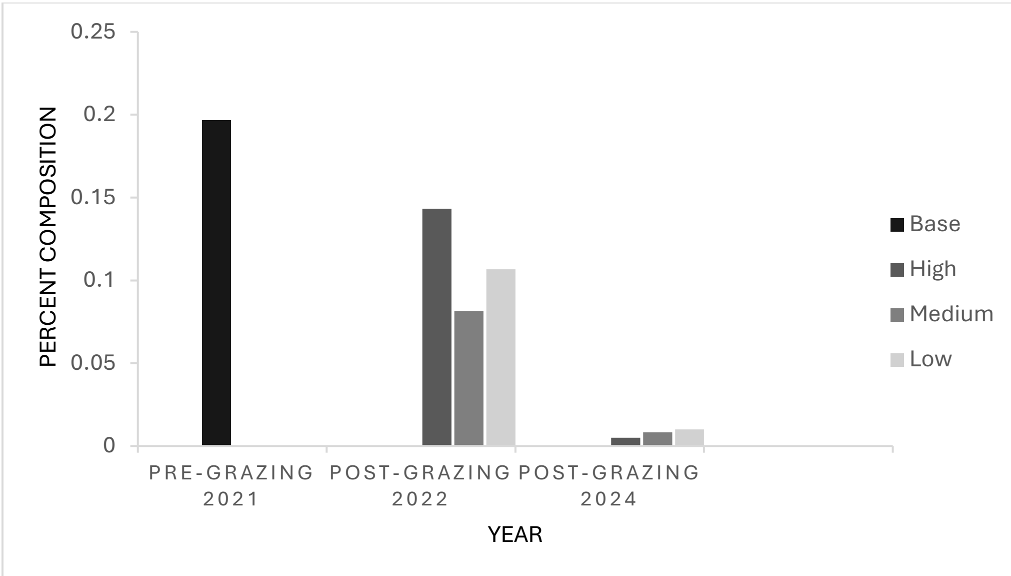

Figure 4.4 Fixed effects interaction (*P* = 0.93) between grazing treatments of High (14-head), Medium (7-head) and Low (4-head) densities and year of pre-grazing 2021 (base), post-grazing 2022, and post-grazing 2024 on relative abundance of grass-like species. Pre-grazing sampling was not conducted at the experimental unit level and used as an initial comparison for post-grazing years.

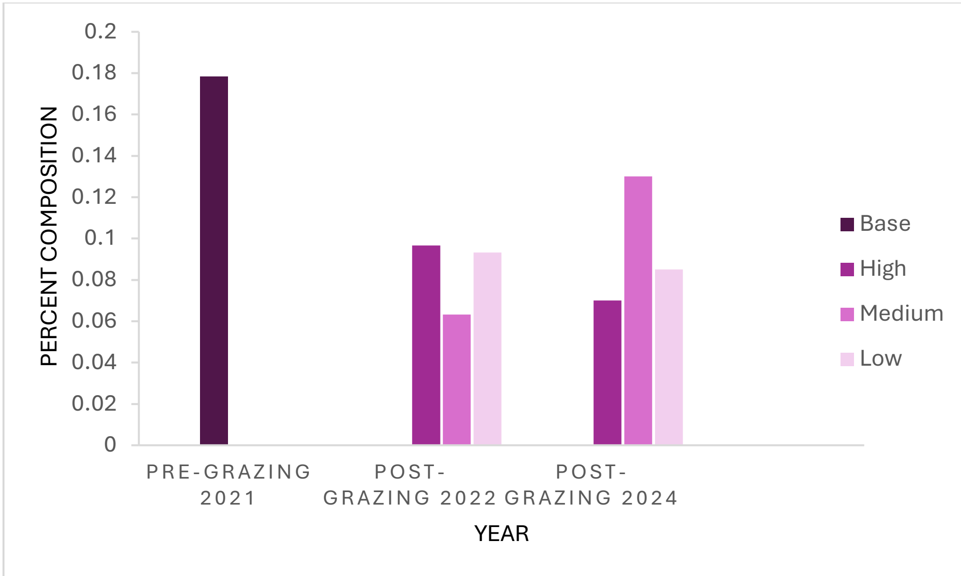

Figure 4.5 Fixed effects interaction (*P* = 0.40) between grazing treatments of High (14-head), Medium (7-head) and Low (4-head) densities and year of pre-grazing 2021 (base), post-grazing 2022, and post-grazing 2024 on relative abundance of other forbs. Pre-grazing sampling was not conducted at the experimental unit level and used as an initial comparison for post-grazing years.

Table 4.4 Nutritive value of forage measured within High (14-head), Medium (7-head), and How (4-head) stocking rate treatment paddocks.

Fixed Effects	**High**	**Medium**	**Low**	**P-value**
		Least Square Means (%)		
LBDM[1]	96.3 ± 0.002	96.3 ± 0.002	96.4 ± 0.002	0.90
OM[2]	93.1 ± 0.003[c]	94.6 ± 0.003[a]	94.0 ± 0.003[b]	0.01
NDF[3]	64.7 ± 0.02	63.1 ± 0.02	62.9 ± 0.02	0.85
ADF[4]	36.4 ± 0.01	35.7 ± 0.01	36.8 ± 0.01	0.78
CP[5]	5.70 ± 0.77	5.99 ± 0.77	5.74 ± 0.77	0.92
CT[6]	5.66 ± 2.16	1.65 ± 2.16	3.49 ± 2.16	0.44

[1]Lab Dry Matter, [2]Organic Matter, [3]Neutral Detergent Fiber, [4]Acid Detergent Fiber, [5]Crude Protein, [6]Condensed Tannins. Means followed by the same lowercase letters within the columns (treatment) within each response variable (nutritive value) are not different.

APPENDIX

APPENDX A-1. Figure 3.6 Percentage of Livestock Grazing Management among Producers

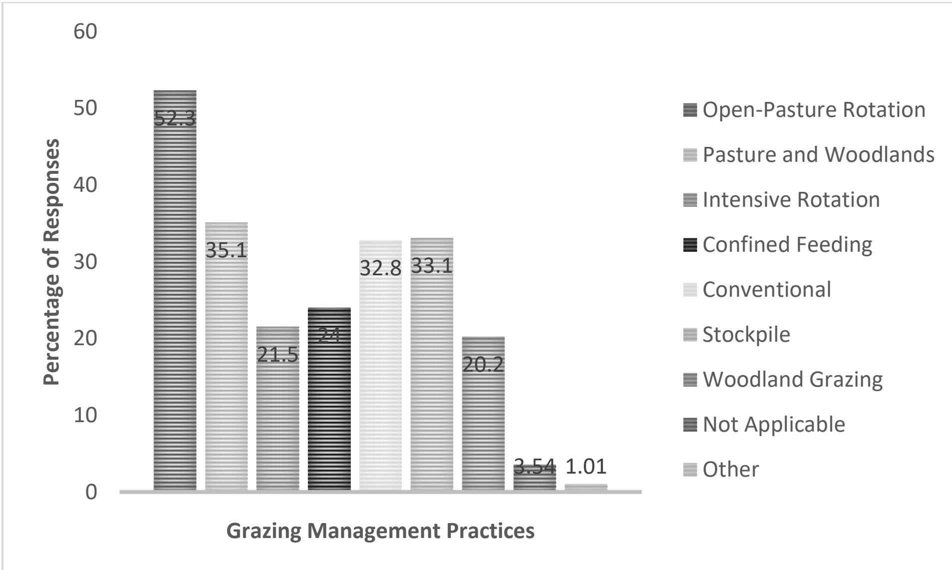

Figure 4. Percentage of grazing management among Missouri livestock producers and landowners. Grazing management practices consisted of rotational grazing between different open pastures (*open-pasture rotation*), rotational grazing between pasture and woodlands (*pasture and woodlands*), managed intensive rotational grazing with 8 or more paddocks (*intensive rotation*), confined feeding for 45 or more consistent days (*confined feeding*), continuous grazing in open pasture (*conventional*), stockpile grazing in pastures (*stockpile*), woodland/forested grazing (*woodland grazing*), individuals who do not participate in grazing management practices (*not applicable*), and other grazing management practices (*other*). Percentages represent cumulative value of multiple responses and therefore do not equal 100%.

APPENDX A-2. Figure 3.7 Livestock Rotational and Woodland Grazing among Missouri Producers within Tree Canopy Covers

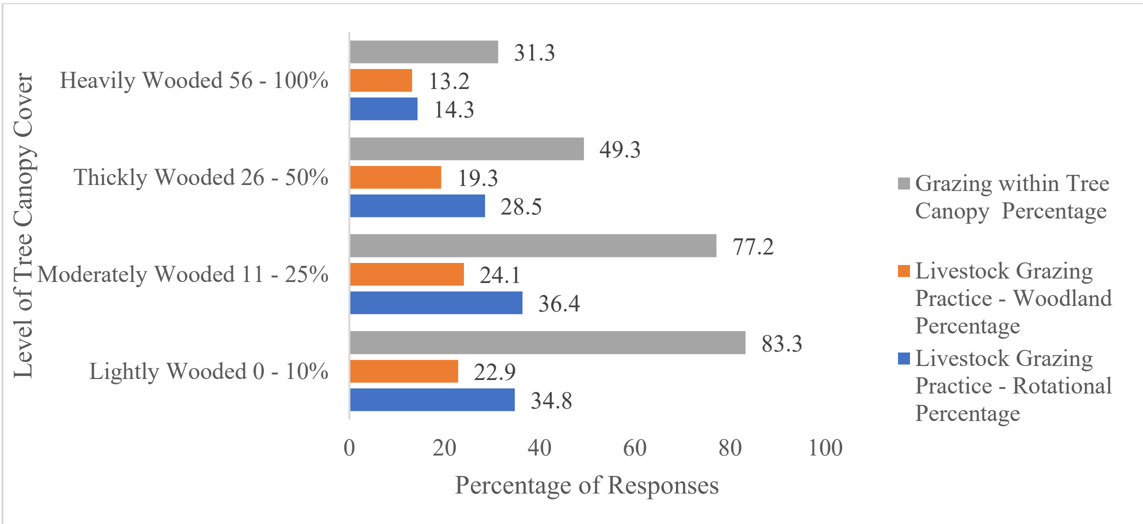

Figure 3. Percentage of Missouri producers who indicated the grazing of wooded areas within various tree canopy covers. Percentages represent cumulative value of multiple responses and therefore do not equal 100%.

APPENDX B. University of Missouri-Columbia Institutional Review Board Approval Letter #2037123

Institutional Review Board
University of Missouri-Columbia
FWA Number: 00002876
IRB Registration Numbers: 00000731, 00009014

310 Jesse Hall
Columbia, MO 65211
573-882-3181
irb@missouri.edu

December 11, 2020

Principal Investigator: Ashley Christine Conway
Department: School of Natural Resources

Your IRB Application to project entitled Investigating the Potential of Woodland Silvopasture Systems: Prevalence, Practices, Perceptions and Performance was reviewed and approved by the MU Institutional Review Board according to the terms and conditions described below:

IRB Project Number	2037123
IRB Review Number	284344
Funding Source	North Central Region Sustainable Agriculture Research and Education (SARE)
Initial Application Approval Date	December 11, 2020
IRB Expiration Date	December 11, 2021
Level of Review	Exempt
Project Status	Active - Exempt
Exempt Categories (Revised Common Rule)	45 CFR 46.104d(2)(i)
	45 CFR 46.104d(2)(ii)
Risk Level	Minimal Risk
Approved Documents	Updated recruitment script with clarification of research study status Consent letter to be included with the mailed survey.

Note: Please submit an amendment when you are ready to submit your documents.

The principal investigator (PI) is responsible for all aspects and conduct of this study. The PI must comply with the following conditions of the approval:

1. **COVID-19 Specific Information**

Enrollment and study related procedures must remain in compliance with the University of Missouri regulations related to interaction with human participants following guidance at research.missouri.edu/about/covid-19-info.php
In addition, any restarting of in-person research activities must comply with the policies and guiding principles provided at research.missouri.edu/about/research-restart.php, including appropriate approvals for return to work authorization for individuals as well as human subject research projects.

2. No subjects may be involved in any study procedure prior to the IRB approval date or after the expiration date.
3. All study changes must be IRB approved prior to implementation utilizing the Exempt Amendment Form.
4. The Annual Exempt Form must be submitted to the IRB for review and approval at least 30 days prior to the project expiration date to keep the study active or to close it.
5. Maintain all research records for a period of seven years from the project completion date.

If you are offering subject payments and would like more information about research participant payments, please click here to view the MU Business Policy and Procedure: http://bppm.missouri.edu/chapter2/2_250.html

If you have any questions or concerns, please contact the MU IRB Office at 573-882-3181 or email to muresearchirb@missouri.edu.

Thank you,
MU Institutional Review Board

APPENDX C. Center for Agroforestry Woodland Silvopasture Survey Peer-Test Recruitment

UNIVERSITY OF MISSOURI
CENTER FOR AGROFORESTRY
RESEARCH STUDY

WOODLAND SILVOPASTURE ADOPTION

FOCUS GROUP RECRUITMENT

INTERESTED PARTICIPANTS, PLEASE CONTACT FOR REGISTRATION

VARIOUS LOCATION AVAILABLE BELOW

Southwest Research Center
Mt. Vernon, MO
Tuesday, August 17, 2021
10:30 AM – 12:00 PM

Lincoln University
Jefferson City, MO
Thursday, August 19, 2021
5:30 PM – 7:00 PM

University of Missouri
Columbia, MO
Friday, August 20, 2021
5:30 PM – 7:00 PM

Virtual Option
Monday, August 23, 2021
10:30 AM – 12:00 PM

LIVESTOCK PRODUCERS AND FOREST LANDOWNERS

The Center for Agroforestry at the University of Missouri is ***recruiting focus group participants*** for a woodland silvopasture adoption research study, to assess livestock producers and forest landowners' present knowledge and perspectives of silvopasture practices, and barriers to adoption. Focus groups will be held in-person and virtually, with participants to receive compensation for participation [***In-person $25/Virtual $20 Visa Gift Cards***].

Interested participants, please contact Ashley Conway, acconway@missouri.edu and/or Kendra Esparza-Harris kexb5@missouri.edu for registration. Additionally, registration can be completed via phone/voicemail: (573) 882-6304

APPENDX D. Center for Agroforestry Woodland Silvopasture Survey

Woodland Silvopasture Perceptions and Practice Among Missouri Farmers and Landowners

The University of Missouri, Center for Agroforestry, invites you to respond to a **short** survey to help assess current woodland management and silvopasture practices in Missouri. We aim to capture Missouri livestock producers and forest landowners' present knowledge and perspectives of silvopasture practices, and barriers to adoption. The **voluntary** survey will take 10-15 minutes, and all responses will remain anonymous. In completing the survey, you acknowledge that you are 18 years old or older and agree to participate in this research survey.

In addition to the survey, an optional mailing card is enclosed to provide your contact information, if you wish to participate in a silvopasture peer-learning network (PLN) or to be informed about the results of the survey. Any contact information provided will be confidential. Further questions about your rights as a research participant can be directed to the University of Missouri Institutional Review Board (IRB) by calling 573.882.3181 and/or email irb@missouri.edu. In advance thank you for your participation!

Please scan the QR code if prefer to participate in the survey online. Traducción al español disponible.

For additional information, please contact: Kendra Esparza-Harris, Graduate Student Researcher (kexb5@missouri.edu) and/or Ashley Conway, Assistant Research Professor (acconway@missouri.edu)

Section 1: Agricultural Production System and Livestock Grazing Management

1. Identify which categories of agricultural products you produce whether for personal and/or commercial use. Please ***select all that apply*** within the table provided. If other, please specify. ***Skip if do not produce products***.

Agricultural Products

***Personal** (Household Consumption and Usage)*	***Commercial** (Produced for Sale)*
☐ Annual Vegetables	☐ Annual Vegetables
☐ Cereals/Grains	☐ Cereals/Grains
☐ Perennial Produce	☐ Perennial Produce
☐ Non-Timber Forest Products (Fruits/Nuts)	☐ Non-Timber Forest Products (Fruits/Nuts)
☐ Timber Products	☐ Timber Products
☐ Livestock (Meat)	☐ Livestock (Meat)
☐ Livestock (Non-Meat) [i.e., Eggs]	☐ Livestock (Non-Meat) [i.e., Eggs]
☐ Other Edible Products, specify [____________]	☐ Other Edible Products, specify [____________]
☐ Other Non-Edible Products, specify [i.e., Hay] [____________]	☐ Other Non-Edible Products, specify [i.e., Hay] [____________]

2. Indicate the type(s) of animals you manage in your livestock operation **(*select all that apply*)**:

☐ Beef Cattle	☐ Sheep	☐ Hogs	☐ Other [____________]
☐ Dairy Cattle	☐ Goats	☐ Poultry	☐ Not Applicable (N/A)

3. Select one or more options that best describe your grazing management practices **(*select all that apply*)**:

☐ Rotational grazing between different open pastures	☐ Continuous grazing in open pasture
☐ Rotational grazing between pasture and woodlands	☐ Stockpile grazing in pastures
☐ Managed intensive rotational grazing (8 or more paddocks)	☐ Woodland/forested grazing
☐ Confined feeding (45 or more consistent days)	☐ Not applicable (N/A)

☐ Other, please specify [____]

4. Which months of the year do your livestock graze forage **(*select all that apply*)**, ***skip if do not own livestock***:

☐ January	☐ February	☐ March	☐ April
☐ May	☐ June	☐ July	☐ August
☐ September	☐ October	☐ November	☐ December

5. Identify the predominant forage species in your grazing and/or land management system **(*select all that apply*)**:

Cool Season Grasses	**Warm Season Grasses**	**Legumes**	**Additional Feed Options**
☐ Tall Fescue	☐ Big Blue Stem	☐ Alfalfa	☐ Hay/Mixed Grass Hay
☐ Orchardgrass	☐ Little Blue Stem	☐ White Clover	☐ Haylage/Silage
☐ Bromegrass	☐ Indiangrass	☐ Red Clover	☐ Cereal/Blended Grains
☐ Kentucky Bluegrass	☐ Eastern Gamagrass	☐ Alsike Clover	☐ Co-products (Corn)
☐ Reed Canarygrass	☐ Switchgrass	☐ Birdsfoot Trefoil	☐ Byproducts (Distillers)
☐ Annual Grasses	☐ Annual Grasses	☐ Annual Legumes	☐ Crop Residue

☐ Other (please specify, i.e., Timothygrass/Bermudagrass/Tree Nuts/Culled Fruit/Vegetable) [____]

☐ Not Applicable (N/A)

Section 2: Acreage of Land and Woodland Area Description

1. Identify approximately, how many total acres of land owned:

☐ 0 - 9	☐ 50 - 100	☐ 251 - 500	☐ 1,000 +
☐ 10 - 49	☐ 101 - 250	☐ 501 - 999	☐ Not Applicable (N/A)

2. Select the average number of acres you lease/rent from an external source, <u>solely</u> for production:

☐ 0 - 9	☐ 50 - 100	☐ 251 - 500	☐ 1,000 +
☐ 10 - 49	☐ 101 - 250	☐ 501 - 999	☐ Not Applicable (N/A)

3. Estimate the percentage of land that you own and/or lease which is wooded/forested:
   - ☐ 0 – 25% ☐ 26 – 50% ☐ 51 – 75% ☐ 76% + ☐ Not Applicable (N/A)

4. With consideration of the wooded/forested acreage on the land indicated above, indicate which category **best** describes each **level tree canopy cover** (**percent shade**) present **(*select all that apply*)**:
   - ☐ Lightly Wooded (0 – 10%) ☐ Moderately Wooded (11 – 25%) ☐ Thickly Wooded (26 – 60%) ☐ Heavily Wooded (61 – 100%) ☐ Not Applicable (N/A)

5. For each **level of tree canopy cover,** select the **best** description for the **understory vegetation** condition during the growing season. Additionally for each level, indicate whether previously or currently grazed (***yes*|*no***) by livestock. ***If indicated not applicable (N/A) in the previous question (#4), please skip to question #6.***

Tree Canopy/Shade Cover	**Understory Vegetation (Low-grazing Brush)**			**Grazed**
Lightly Wooded (0 – 10%)	☐ Bare	☐ Moderate	☐ Dense	Yes | No
Moderately Wooded (11 – 25%)	☐ Bare	☐ Moderate	☐ Dense	Yes | No
Thickly Wooded (26 – 60%)	☐ Bare	☐ Moderate	☐ Dense	Yes | No
Heavily Wooded (61 – 100%)	☐ Bare	☐ Moderate	☐ Dense	Yes | No

- Bare: little to no vegetation within the understory
- Moderate: medium to lush vegetation within the understory that is walkable with minimal to no touching of brush
- Dense: thick/compact vegetation within the understory which is impenetrable without equipment

6. Select **all** the forest management activities you have conducted on your forested acreage within the last 10 years:
   - ☐ Commercial/for-profit logging
   - ☐ Non-commercial thinning (timber stand improvement [TSI])
   - ☐ Mechanical/physical clearing of brush
   - ☐ Other (please specify) [__________________]
   - ☐ Prescribed burn
   - ☐ Chemical removal of invasive species
   - ☐ Cultural clearing of brush
   - ☐ Not applicable (N/A)

Section 3: Perceptions and Barriers of Woodland Silvopasture

1. Select the average number of years you have in experience with **agriculture** (crops, livestock, tree products):
   - ☐ 0 - 5 ☐ 15 - 24 ☐ 35 - 44 ☐ 55 +
   - ☐ 6 - 14 ☐ 25 - 34 ☐ 45 - 54 ☐ Prefer not to answer

2. Select the average number of years you have in experience with **forest management**:
   - ☐ 0 - 5 ☐ 15 - 24 ☐ 35 - 44 ☐ 55 +
   - ☐ 6 - 14 ☐ 25 - 34 ☐ 45 - 54 ☐ Prefer not to answer


Figure A


Figure B

Photo Credit: Dusty Walter, UMCA

Silvopasture is an agroforestry practice which involves the integration of trees and/or shrubs, crops and/or forage, and livestock as a management system. Woodland silvopasture incorporates the management of livestock and forage within existing, non-planted shrub/tree stands (Figures A and B). For development of a woodland silvopasture system, natural forests and woodlands are ecologically modified through strategic thinning of timber stands to facilitate growth of forage plants in the understory of the canopy.

Woodland silvopasture has the potential to adapt within a variety of forests stands, such as hardwoods and conifers. It also facilitates the production of various forage (grass and legume) varieties for the grazing of different livestock and wildlife species.

For each of the following questions below, indicate your agreement and/or disagreement with the statements provided in reference to the informational graphic (above). Please keep your operation and owned/leased land in mind to answer.

3. Are you currently, or have you in the past, incorporated silvopasture management on your farm?

☐ Yes ☐ No ☐ Not Sure

If **yes**, please record the number of years ____________________

4. Indicate your agreement and/or disagreement with the following statements on the perception of woodland silvopasture, in reference to the informational graphics provided.

Perception of Woodland Silvopasture	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Integration of livestock in woodlands is ecologically beneficial.	1	2	3	4	5
Integration of livestock in woodlands is ecologically detrimental.	1	2	3	4	5
Livestock are a useful woodland management tool.	1	2	3	4	5
Integration of livestock in woodlands is different than woodland grazing.	1	2	3	4	5

Integration of livestock in woodlands is NOT suitable for my operation.	1	2	3	4	5

5. Indicate your agreement and/or disagreement with the following benefits of woodland silvopasture.

Benefits of Woodland Silvopasture	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Natural resources conservation	1	2	3	4	5
Maximize production acreage	1	2	3	4	5
Woodland management	1	2	3	4	5
Aesthetics & recreation	1	2	3	4	5
Animal health & performance	1	2	3	4	5
Wildlife habitat restoration	1	2	3	4	5
Revenue diversification	1	2	3	4	5

6. Within each subcategory, review the following benefits, and indicate the level of priority for each benefit as an opportunity of woodland silvopasture. ***Please choose an option for each category.***

Opportunity of Woodland Silvopasture	Low Priority	Somewhat Priority	Neutral	Moderate Priority	Essential Priority
Environmental					
Improve soil health	1	2	3	4	5
Management of invasive species	1	2	3	4	5
Forest health management	1	2	3	4	5
Establish wildlife habitats	1	2	3	4	5
Economic					
Increase short-term return	1	2	3	4	5
Revenue diversification	1	2	3	4	5
Increase land value (NPV)	1	2	3	4	5
Social					
Aesthetics of farm and/or land	1	2	3	4	5
Recreational services	1	2	3	4	5
Intergenerational stewardship	1	2	3	4	5
Social responsibility	1	2	3	4	5
Production					
Improve timber value	1	2	3	4	5
Reduce seasonal environmental stress for livestock	1	2	3	4	5
Diversify forage production	1	2	3	4	5
Increase pasture management	1	2	3	4	5

Other *(if choose to, in the spaces provided specify and rank benefits, in addition to the choices listed)*

	1	2	3	4	5
	1	2	3	4	5
	1	2	3	4	5
	1	2	3	4	5

7. Indicate your agreement and/or disagreement with the following barriers to woodland silvopasture adoption. ***Please choose an option for each category.***

Barriers of Woodland Silvopasture	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

Establishment

Conservation program restrictions	1	2	3	4	5
Financial investment	1	2	3	4	5
Required thinning of forest	1	2	3	4	5
Land ownership and/or tenure	1	2	3	4	5
Limited knowledge of systems	1	2	3	4	5
Other (specify)	1	2	3	4	5

Management

Required forest management	1	2	3	4	5
Minimal animal experience	1	2	3	4	5
Resource availability	1	2	3	4	5
Labor/time management	1	2	3	4	5
Market access for saleable products	1	2	3	4	5
Other (specify)	1	2	3	4	5

8. Based on your understanding, are you likely to implement woodland silvopasture management on your farm and/or land?

☐ Yes ☐ No

9. In response to the previous question (#6), indicate the likelihood for each of the following options to influence your adoption of woodland silvopasture.

Adoption of Woodland Silvopasture	Extremely Unlikely	Unlikely	Neutral	Likely	Extremely Likely
Potential to lease/contract woodlands	1	2	3	4	5
Environmental impact	1	2	3	4	5
Minimal knowledge of silvopasture systems	1	2	3	4	5
Feasibility of establishment	1	2	3	4	5

Lack of interests in woodland silvopasture	1	2	3	4	5
Technical assistance/informational trainings	1	2	3	4	5
Other (specify)	1	2	3	4	5

In the following space, please provide any additional comments and/or responses regarding your perception and/or adoption of woodland silvopasture.

Demographics [Section Optional and Anonymous]:

1. What is your gender identity?
   - ☐ Male
   - ☐ Female
   - ☐ Non-binary/Gender neutral
   - ☐ Prefer not to answer

2. Identify your age range.
   - ☐ 18 – 25
   - ☐ 26 – 35
   - ☐ 36 – 45
   - ☐ 46 – 55
   - ☐ 56 – 65
   - ☐ 66 – 75
   - ☐ 76 and older
   - ☐ Prefer not to answer

3. Race/Ethnic Identity: Please select all that apply.
   - ☐ White or European American
   - ☐ American Indian or Alaska Native
   - ☐ Native Hawaiian or Pacific Islander
   - ☐ Other [Please identify:]
   - ☐ Black or African American
   - ☐ Hispanic/Latino
   - ☐ Asian
   - ☐ Prefer not to answer

4. What is the **highest level** of education you have received?
   - ☐ Some high school
   - ☐ High school graduate (or equivalent)
   - ☐ Trade or vocational degree
   - ☐ Some college (1-4 years, associate degree)
   - ☐ Bachelor (BA, BS, AB)
   - ☐ Masters (MS, MA)
   - ☐ Higher degree (MD, JD, PhD, EdD)
   - ☐ Prefer not to answer

5. Within the last five years, did farming account for the majority source of your annual household income?
   - ☐ Yes
   - ☐ No

- ☐ Prefer not to answer

6. Within the last five years, what was your approximate gross income from your farming operation?
   - ☐ Net loss/no income
   - ☐ Less than $2,500
   - ☐ $2,500 to $8,999
   - ☐ $9,000 to $29,999
   - ☐ $30,000 to $69,999
   - ☐ $70,000 to $99,999
   - ☐ $100,000 or more
   - ☐ Prefer not to answer

The Center for Agroforestry would like to thank you for your feedback and appreciates your time in completion of the **voluntary** survey to assess current woodland management and silvopasture practices in Missouri. As previously stated, all responses will remain anonymous.

Additionally, as mentioned, an optional mailing card is provided for your contact information if you wish to participate in a silvopasture peer-learning network (PLN) and/or to receive additional information about this research and related projects. Furthermore, any contact information provided will be confidential, and will not be distributed to third parties or included in additional research without your consent.

For additional information, please contact:

- ❖ *Kendra Esparza-Harris, Graduate Student Researcher, (kexb5@missouri.edu)*
- ❖ *Ashley Conway, Assistant Research Professor, (acconway@missouri.edu)*

APPENDX E. University of Missouri-Columbia Institutional Review Board Approval Letter Project #2090473

Institutional Review Board
University of Missouri-Columbia
FWA Number: 00002876
IRB Registration Numbers: 00000731, 00009014

310 Jesse Hall
Columbia, MO 65211
573-882-3181
irb@missouri.edu

October 17, 2022

Principal Investigator: Kendra Esparza-Harris
Department: School of Natural Resources

Your IRB Application to project entitled Adaptive Strategies of Pastoral and Agricultural Communities for Management of Livestock Grazing Systems in the Commons of Senegal was reviewed and approved by the MU Institutional Review Board according to the terms and conditions described below:

IRB Project Number	2090473
IRB Review Number	374772
Funding Source	Boren Fellowship Program College of Agriculture, Food, and Natural Resources (CAFNR)
Initial Application Approval Date	October 17, 2022
IRB Expiration Date	October 17, 2023
Level of Review	Exempt
Project Status	Active - Exempt
Exempt Categories (Revised Common Rule)	45 CF46.104d(2)(ii)
Risk Level	Minimal Risk
HIPAA Category	No HIPAA
Approved Documents	Informed Consent & Assent - Consent (Exempt Studies Only): #616138 Informed Consent & Assent - Consent (Exempt Studies Only): #616139 Other Study Documents - Interview Questions: #612939 Recruitment Materials - Recruitment Script: #616140

The principal investigator (PI) is responsible for all aspects and conduct of this study. The PI must comply with the following conditions of the approval:

6. No subjects may be involved in any study procedure prior to the IRB approval date or after the expiration date.
7. All study changes must be IRB approved prior to implementation utilizing the Exempt Amendment Form.
8. Major noncompliance must be reported to the MU IRB on the Event Report within 5 business days of the research team becoming aware of the deviation. Major noncompliance are deviations that caused harm or have the potential to cause harm to research subjects or others, and have or may have affected subject's rights, safety, and/or welfare. Please refer to the MU IRB Noncompliance policy for additional details.
9. The Annual Exempt Form must be submitted to the IRB for review and approval at least 30 days prior to the project expiration date to keep the study active or to close it.
10. Maintain all research records for a period of seven years from the project completion date.

If you are offering subject payments and would like more information about research participant payments, please click here to view the MU Business Policy and Procedure: http://bppm.missouri.edu/chapter2/2_250.html

If you have any questions or concerns, please contact the MU IRB Office at 573-882-3181 or email to muresearchirb@missouri.edu.

Thank you,
MU Institutional Review Board

APPENDX F. Comparative Case Study Verbal Consent Statement

Research Project Verbal Consent Statement

You have been invited to participate in the following research project and we wanted to inquire of your consent. For participation you must be 18 years of age or older. Your participation in the project is voluntary, and you may stop participation in the study at any time. We are implementing a research project throughout the northeast and southeastern regions of Senegal, to understand the strategies utilized to improve the resilience of pastoralism in Senegal, and the state of conflict between pastoralists and agriculturalists. As well, we are interested in which strategies have the potential to improve sustainability and resilience of pastoralism within various ecological regions. For the project, the goal is to discuss and develop strategies which can be used within local communities, organizations, and the ministry to facilitate resilience within transhumance corridors. As a participant, your involvement will include an *individual (focus group)* audio recorded discussion within the areas of pastoralism and agriculture, for a set one-hour time frame. For your time and effort, we will offer compensation in the form of a gift following participation in study.

The information you provide will be kept confidential and only the research team will have access to identifiable information such as your name and age. Identifiable information will not be included in the audio recordings but will be written down. Consent includes the permission for audio recordings and to use photos for research and educational purposes taken throughout the project. To move forward, we require a consent of your participation by answering yes, I consent, or no, I do not consent. If you have questions about this study, you can contact Dinguere Ba, or Gora Beye within the Ministére de L'Elevage et des Productions to connect with the University of Missouri researcher at (*+221 77 616 0429*).

Upon request, a copy of this consent can be provided for your records. We appreciate your consideration to participate in this study.

APPENDX G. Comparative Case Study Semi-Structured Interview Facilitative Questions

Research Project Semi-Structured Interview Discussion
Sunday, October 23rd – Friday, January 25th

Semi-structured Interviews

- **What is your name (first and last name)?**
- **How old are you, or what year were you born)?**
- **Where are you from?**
- **What do you do for work?**
  - **Pastoralists –** nomadic, semi-sedentary, sedentary
  - **Agriculturalists –** solely farm, inclusion of trees, ownership of animals

Pastoralists (Herders)

1. **What is the importance of pastoralism (tradition of herding) to you and your family?**
   I. What is the importance of pastoralism to Senegal?
   II. What impact does pastoralism have on the land and resources?

2. **What type of animals do you herd (species, (cow/sheep/goat), sex (male/female), age (babies), stage (pregnant)?**
   I. Do you own the animals, or do you herd on the behalf of someone else?
   II. When do you reproduce the animals?
   III. From the heard, what type of animal products do you sell (meat, milk, yogurt)

3. **Explain the way you herd your animals for resources – food and water?**
   I. Which path(way) corridor do you use to migrate (travel) for resources? If do not travel, how far do you travel locally for resources?
   II. Why have you chosen this path(way) to travel? When do leave to travel?
   III. What has changed within the past (few) years in the way you herd? Do you leave earlier and/or later? What has changed within the pattern (the way chosen)?

4. **When you herd, how accessible are resources during times of migration (fodder and water)?**
   I. Which resources are limited throughout travel within the corridor?
   II. How have your access to resources changed over time? What type of forage is available for livestock to graze (i.e., grass, crop residue, fodder trees)?

5. **What overall challenges are endured through pastoralism (herding)?**
   I. What challenges occur in production of animals?
   II. What conditions and/or stress do your animals encounter (heat stress, lack of water, predators)?

III. How have these challenges impacted animal reproduction, production, the market, and yourself?

6. **Which of the following stressors have affected pastoralism (cause difficulty or tension on system) – climate change (temperature/desertification), bush fire, drought (rain shortage), diseases, development (pollution), intensified agriculture?**
   I. Within the herd, which group/type of animals are more impacted (affected) by the threats?

7. **What strategies(changes) have you tried to combat these stressors and increase your access to resources (forage and water)?**
   I. Of the strategies/changes, how have the worked or not worked?

8. **An important aspect (part) of transhumance corridors are the social relationships with other herders and farmers. Why are the relationships between herders – herders and herders – farmers important?**

   I. How have these relationships changed with local and regional herders and farmers?
   II. What causes conflict between herders - herders and herders – farmers?
   III. How have changes in movement through the transhumance corridors, or interaction with herders and farmers affected your or animal production?
   IV. What has happened because of this conflict (damage of property, generational conflict)?
   V. What strategies/changes have been attempted to reduce conflict between herders – herders and herders – farmers?

9. **Government and local agencies have implemented projects to create permanent lines for the corridor, create boreholes, and fodder banks. Do you feel these strategies are helpful or restrictive?**

10. **What assistance or resources do you have to develop strategies? What assistance or resources do you think will help in the resilience of the system?**

Agriculturalists (Farmers)

1. **What is the importance of agriculture (tradition of farming) to you and your family?**
   I. What is the importance of agriculture to Senegal?
   II. What impact does agriculture have on the land and resources?

2. **What type of crops do you produce (crops, fruit, vegetable), for personal or commercial production?**
   I. Do you own the land, or do you produce crops on someone’s land?

II. When do you harvest the crops?
III. What type of crop products do you sell (crop fruit, vegetables)

3. **Explain the way you farm within the operation?**
    I. Which techniques have you used within your farming operation?
    II. Why have you chosen these techniques?
    III. What has changed within the past (few) years in the way you farm? Have you experienced a change in the timing of planting or harvesting crops?

4. **When you farm, how accessible are resources during times of production (soil, seeds, water, equipment, labor)?**
    I. Which resources are limited throughout the farming season?
    II. How have your access to resources changed over time? What type of crops are you able to produce?

5. **What overall challenges are endured through farming, currently versus the past?**
    I. What challenges occur in the production of crops?
    II. What conditions and/or stress do your crops encounter (decreased soil health, lack of water, pest)?
    III. How have these challenges impacted the production of crops, the market, and yourself?

6. **Which of the following stressors have affected farming (cause difficulty or tension on system) - climate change (temperature/desertification), bush fire, drought (rain shortage), diseases, development (pollution), intensified agriculture?**
    I. Among the production, which type of crops are more impacted (affected) by the threats?

7. **What strategies (changes) have you tried to combat these stressors and increase your access to resources (soil, seeds, water, equipment, labor)?**
    I. Of the strategies/changes, how have they worked or not worked?

8. **Transhumance corridors are an important way of livestock production in Senegal which continues through the social relationships between herders and farmers. Why are the relationships between herders – herders and herders – farmers important?**
    I. How have these relationships changed with local and regional herders and farmers?
    II. What causes conflict between herders – herders and herders – farmers?
    III. How has movement through the transhumance corridors, or interaction with pastoralists affected your farming and/or gardening, or animal production (cool/dry, rainy, hot season)?
    IV. What has happened because of this conflict (damage of property, generational conflict)?
    V. What strategies have been attempted to reduce conflict between herders – herders and herders – farmers?

9. **Government and local agencies have implemented projects to create permanent lines for the corridor, create boreholes, and fodder banks. Do you feel these strategies are helpful or restrictive?**

10. **What assistance or resources do you have to develop strategies? What assistance or resources do you think will help in the resilience of the system?**

Focus Groups

- **What is your name (first and last name)?**
- **How old are you, or what year were you born)?**
- **Where are you from?**
- **What do you do for work?**
    - **Pastoralists –** nomadic, semi-sedentary, sedentary
    - **Agriculturalists –** solely farm, inclusion of trees, ownership of animals
- **What is the average size of herds (max/min) in the village?**
- **What is the average size of farms (max/min)?**
- **How far is the closest market to sell products?**

1. **What are the common products produced (animals and crops) for consumption and selling (milk, vegetables, peanuts, corn, rice)?**
    I. How are the different ages of animals affected by the migration or way of securing feed?
    II. How are the different crops affected by the changes in animal migration and limited resources?
    III. How have the market, price of products changed with the change in available resources?

2. **Transhumance corridors are an important way of livestock production in Senegal which continues through the social relationships between herders and farmers. Why are the relationships between herders – herders and herders – farmers important?**
    I. How are the corridors maintained and what are the benefits and challenges?
    II. How have these relationships changed over the years?
    III. What causes conflict between herders – herders and herders – farmers?
    IV. What has happened because of this conflict (damage of property, generational conflict)?

3. **In recent years, pastoralism/migration patterns have been more prominent in the Southern region of Senegal, why is this? Has this caused an increase in conflict or issues (problems)?**
    I. What conflict has this caused with organizations such as the forestry department (Eaux et Foret) or local authorities?

4. **Government and local agencies have implemented projects to create permanent lines for the corridor, create boreholes, and fodder banks. Do you feel these strategies are helpful or restrictive?**

5. **What strategies have been utilized to mitigate conflict resolution between herders and farmers? What strategies do you think would assist in conflict resolution and resilience?**

6. **An adaptive strategy used in other countries is silvo-pasture, have you heard of or know the term silvopasture?**
   I. Definition: the components of intentional management of natural resources (trees, forage, and animals) to maintain resources.
   II. What is the difference between silvopasture and pastoralism?
   III. An example of silvopasture would be a collaborative establishment of an alley crop system (planting fodder trees within crops) to provide fodder and shade for animals, manure for soil fertility and clearing of excess crop residue following harvest. What would be the benefit of such a system
   IV. What would be the challenges?

APPENDX H. Comparative Case Study Codebook and Case Justification

<u>Senegal Resource Management Codebook</u>

Deductive – in vivo – line by line coding

Research Objectives

1. Identify the adaptive strategies employed by pastoral and agricultural communities to manage stressors within the commons.
2. Assess the potential of silvopasture as a strategy for community-oriented land-use management of the commons.

Research Questions

1. What <u>adaptive strategies</u> have participants adopted to mitigate the <u>stressors</u> on <u>communal resources</u>?
2. What are the <u>participants' views</u> surrounding tensions (barriers and facilitators) between pastoralists and farmers?
3. What are the <u>participant's perceptions</u> of silvopasture components and its <u>utility</u> within Senegal?

Preliminary (Initial) Codes

- Adaptive strategies – *activities or plans informally or formally developed to maintain livelihood practices against challenges or obstacles*
- Stressors – *internal or external stimulus or actions which cause a strain/tension on the pastoral and agricultural livelihood practices*
- Communal resources – natural resources (i.e., water, land, trees) traditionally shared among community members
- Tensions – individual participants distinct perspective (viewpoint) on the tensions between pastoralists and farmers (characteristics or identification of specific pressures)
- Silvopasture perceptions – individual participants awareness (understanding) and interpretation of the practice of silvopasture
- Utility – comprehensive benefits and/or challenges of the integration of silvopasture practice
- Open codes – additional information of interests beyond initial codes listed

Case Study Regions of Focus

Louga (Dahra Jolof) – Northern Tambacounda (Koumpentoum)
Southern Tambacounda (Gouloumbou) – Northern Kolda (Velingara)

Case Study Rationale for Coding and Analysis

Four main cases were developed to represent the four ecological zones within Senegal – Ndioum (Saint Louis Region), Dahra Jolof (Louga Region) and Koumpentoum (Northern Tambaounda), Gouloumbou (Southern Tambacounda Region) and Velingara (Northern Kolda Region), Kedougou (Kedougou Region). An additional region was included to interview the King of Oussouye (Ziguinchor Region). These cases were chosen as they correspond to known transhumance corridors, contain the livelihoods of pastoralists and agriculturalists, and impacted by stressors.

<u>Ndioum (Saint Louis Region)</u>

Ndioum, a regional town within the Podor department is situated in the northern section of the Sain-Louis region. Ndioum is positioned along the route national within close proximity to the Senegal – Mauritania border and Senegal River. The area is known as the sylvo-pastorale zone and has become a permanent homestead for pastoralists to return throughout the rainy season (June – October), trade within the weekly markets, and find community. Agricultural activities are present, mainly throughout the rainy season, but seldomly cause conflict among pastoralists as have a communal understanding. The discussion with participants focused on the challenges experienced in transit throughout the southern regions, climate change, and access to markets to sell an abundance of milk products. The main stressors which have impacted the pastoral livelihoods in the area are the loss of water resource (i.e., damming of Senegal River, intensified agriculture) and climate change, along with minimal opportunities for economic expansion. With the area situated within the Sahel, it is difficult to grow trees which would aid in the adoption of silvopasture. Though, there were mentions of opportunities to include components of silvopasture during the rainy season. ***The interactions with participants mainly contributed to a cultural awareness of the pastoral livelihood and therefore can provide supportive cultural information but does not warrant selection within the analysis to answer the research questions***.

Dahra Jolof (Louga Region) and Koumpentoum (Northern Tambaounda)

The Louga and Northern Tambacounda Region were combined because they consist of one of the major transhumance corridors within Senegal. The Louga region has a dry climate with a long dry season that supports pastoral inhabitants and livestock markets. The Northern Tambacounda region has an economy based primarily on agriculture cash crops such as cotton and peanuts. Between the regions is known as the transition or connection between pastoralism and agriculture. The regions have experienced a significant number of stressors to include climate change, loss of communal resources, urbanization, intensification of agriculture and issues with land tenure which have resulted in persistent conflict between semi sedentary pastoralists, transhumant pastoralists, and agriculturalists. The Senegalese government, non-profit organizations, and international agencies continue to invest in solutions to manage these issues, but the problems have continued to escalate. A main issue that was discussed is with the change in the rainy season. Because the rainy season has shifted, the pastoralists have begun to travel and/or release their animals later in the year which coincides with the timing of crop harvest, thus causing conflict. A solution the government has supported is establishing a permanent transhumance corridor to reduce the undesired interactions and negative fall-out. This case supports the research questions of identifying adaptive strategies and potential of silvopasture as a potential strategy, and therefore would be a beneficial case to include in comparison for analysis.

Gouloumbou (Southern Tambacounda Region) and Velingara (Northern Kolda Region)

Tambacounda is physically the largest of the regions in Senegal, though the northern and southern regions differ ecologically. The southern region of Senegal shares a border with the Kolda and Kedougou regions and shares the Gambia River. Southern Tambacounda and Northern Kolda were joined as a case because of proximity, similarity of livelihood and economy, and ecological characteristics. In these areas, agriculture and forestry are prominent with the inclusion of small ruminants such as goats or non-ruminants (chickens). Traditional (e.g., squash, casava, millet, yams) and colonial cash crop (e.g., peanuts, corn) production are significant a contribute to the economy among local farmers. Besides cash crop agriculture, gardens tend to flourish throughout the entire year because of the amount of water which lasts longer than the northern part of Senegal. As well, forestry conservation is of importance, as tree production products (i.e., cashews, mangoes, baobab, bananas [not a tree]) provide additional income sources. Lastly, the Gambia river supplies opportunities for local fishing for selling and substance. Wildlife such as monkeys, warthogs, and hippos thrive within these areas due to the preserved natural resources. These areas have become a new target for transhumant pastoralists to settle or travel through and have started to cause pressure on communal resources, however a social relationship has allowed a co-existence to persist without conflict. With urbanization in the major road towns and soil health depletion, the main stressors in the area are land availability for agriculture production and resistance of deforestation. ***Significant interests were expressed towards solutions to maximize agriculture, preserve forest resources, and maintain beneficial relationships with pastoralists which warrants selection as a case study for analysis.***

Kedougou (Kedougou Region)

Kedougou, the south-eastern region of Senegal bordered by Mali and Guinea is characterized as a tropical savanna climate. The topography of the region supports agriculture and livestock production equally, as well as wildlife. Wildlife conservation has become a focus in the region and has led to the creation of the Niokolo-Koba National Park and Chimpanzee conservation in Dindefelo. These conservation efforts have not impacted agriculture and livestock production significantly, though have offered an avenue for economic conversion. Integrated livestock grazing practices are prominent in the area but are threatened by the expansion of mining operations which cause toxic water sources, increase in criminal activity, deforestation, and hazardous conditions. As pastoralists in the northern regions have experienced difficulties in the availability of food and water resources, along with safety, transhumance activities have started to trickle down into the area. Though competition for resources has not escalated to the level of other case study areas, work into preservation is key. The potential for silvopasture in this area is high, and there was significant interests and pre-existing knowledge in the concept. However, conflict persists between the Senegalese, government, and mining companies, and less between agriculturalists and pastoralists. ***Information from the region can be useful for background, but because the responses are focused less on conflict between agriculturalists and pastoralists; I chose not to select for inclusion in the analysis.***

Oussouye (Casamance Region)

The Casamance Region is an area between the Gambia and Guinea-Bissau that experiences a tropical savanna climate that supports the diverse ecology, agricultural economy, and tourism. Within the region, the Oussouye commune, known as the Animist Kingdom, is where the ethnic group Jola acknowledges and participates in Animist customs. The community and the Casamance Region have been able to conserve their ecological diversity and limit external stressors. During my visit, I observed integrated grazing practices within rice fields, forests, and along the coastal line. It is supportive of the potential for an expansion of these practices throughout southern Senegal, and a potential case study project within itself. ***However, I collected a single interview within a single community which does not equal the weight of the other case studies. The region will not be included in the analysis but will be included in the report as an example of preserved traditional/cultural grazing practices.***

Each region (case) is experiencing stressors impacting climate change, and subsequently agriculture and pastoral livelihoods, though the focus of the study is to identify adaptive strategies to stressors significantly impacting agriculture and pastoralism. The study also aims to examine how these stressors are impacting agriculturalists and pastoralists conflict. Furthermore, to assess the potential for silvopasture to assist, which requires the possibility of implementation. Thus, the Louga and northern Tambacounda regions and southern Tambacounda and Kolda region provide sufficient evidence as selections to further comparison.

VITA

Kendra received her Bachelor of Science in Animal Science from North Carolina Agricultural and Technical State University with a certificate in Global Studies in May 2013. She continued to earn a Master of Science in Animal Science from the University of Illinois Urbana-Champaign in August 2017. Her research consisted of utilizing a novel GnRH agonist to synchronize and induce ovulation in weaned sows for timed artificial insemination. This work, Effect of Numbers of Sperm and Timing of a Single, Post-cervical Insemination on the Fertility of Weaned Sows treated with OvuGel®, was published in the Journal of Theriogenology.

Following her studies, Kendra expanded her experience in wildlife reproduction through an internship at the Saint Louis Zoo. During her internship, Kendra became growingly interested in the connection between agriculture, conservation, and natural resource management, which prompted her to serve as an Agroforestry Extension Specialist in Peace Corps Senegal. She gained language proficiency, cultural competency, and technical skills that supported her work in disseminating agroforestry and sustainable agricultural techniques among small-holder agriculture and pastoral communities. This work encompassed partnering with the local forestry department, non-profit organizations, and fellow Peace Corps volunteers to host trainings and manage projects on burning awareness and natural resource management. Kendra's work also included empowering women's education, leadership, and economic opportunities in sustainable agriculture by developing a United States Agency for International Development (USAID) – Peace Corps woman Master Farmer. Unfortunately, towards the end of her service, Kendra sustained a work-injury during field trainings, which resulted in her return to the United States.

Once medically cleared to return to work-related activities, Kendra was accepted as a Charlotte R. Schmidlapp Scholar with the Cincinnati Zoo Conservation Research of Endangered Wildlife (CREW), which involved utilizing assisted reproductive technologies to assist captive breeding programs that help to ensure genetic diversity for future reintroduction of species. Shortly thereafter, Kendra was accepted for the National Institute of Food and Agriculture (NIFA) Higher Education National Needs PhD Fellowship in Natural Resources at the University of Missouri-Columbia. Her interdisciplinary doctoral research has centered around integrative strategies towards implementation of the agroforestry practice silvopasture. This has expanded her awareness on Indigenous natural resource practices and historical changes in human natural resource management. Kendra also increased her capacity for project development and implementation, grants management and reporting, and verbal and written communication skills in academic and non-academic settings. To support her research interest, Kendra was a recipient of the following fellowships, grants, and scholarships: the George Washington Carver Matching Assistantship, David L. Boren Fellowship, Dorris D. & Christine M. Brown Fellowship, John D. Bies Travel Scholarship, and Sustainable Agriculture Research and Education Graduate Student (SARE) Grant.

In addition to her doctorate in Natural Resources, Kendra has obtained a graduate minor in International Development and a graduate certificate in Society & Sustainability. Beyond her studies, Kendra has gained experience as a teaching assistant and graduate mentor for Minorities in Agriculture, Natural Resources, and Related Sciences (MANRRS). She also has participated in various student organizations including the Deaton Scholar Food Security Program, Agroforestry and Forestry Graduate Student Association (AFFGSA) and Wildlife and Fisheries Sciences Graduate Student Organization (WAGS GSO).

Following the completion of her coursework, Kendra accepted a position as a Climate-Smart Forestry Program Specialist through the US Forest Service Resource Assistant Program. She has since transitioned to a permanent position serving as the Forest Landowner Outreach Coordinator for the Virginia Department of Forestry. This position aligns with Kendra's passion for engaging with landowners in natural resource management and agroforestry practices.