GOAT DIETARY SELECTIONS, PERFORMANCE AND BROWSING EFFECTS ON A BRUSH-INVADED OAK SAVANNA IN SOUTHWEST WISCONSIN

By

Cherrie Nolden

A thesis proposal submitted in partial fulfillment of

the requirements for the degree of

Master of Science

(Agroecology)

at the

UNIVERSITY OF WISCONSIN-MADISON

2020

Thesis approved by:

John Harrington   Date
Major professor

ABSTRACT

Managed goat browsing is a potential tool for vegetation community restoration projects by precisely applying their food selections and natural behaviors to reopen savanna communities whose midstories have significant aggressive brush and sapling growth due to lack of management. Application of goats for restoration is common in other countries and other parts of the United States, but it is not commonly accepted as a vegetation management tool in the Upper Midwest. Fire, commonly used instead, is not always appropriate due to liability issues, weather conditions and the frequency at which it can be applied. In most instances the application of browsing animals does not have these limitations. This research explores the potential for applying goats as a management tool for brush reduction in Upper Midwest savannas, where aggressive brush is a significant threat to remaining parcels. In this research, goats were rotationally browsed through a randomized complete block design of five replicate blocks with three treatments (Heavy browsing, Light browsing, Control), and a split plot treatment over a three-year period from 2011 to 2013. Vegetation and environmental response data were collected in the spring following the browsing, and goat activity data were collected during the browsing treatments. Pre-browsing vegetation surveys showed no significant differences between treatments. Mixed model ANOVA in SAS showed that by the spring following 3 years of goat browsing, the Heavily browsed treatments were significantly different than Control treatments in many of the vegetation response variables. By 2014, brush height and percent cover decreased, the number of dead woody stems was greater, herbaceous species richness and cover, specifically forbs, increased in Heavily browsed treatments relative to Control treatments. The goats caused no detectable difference in soil compaction or leaf litter reduction. Aggressive forbs as an entire category increased in

Heavily browsed treatments, but no individual invasive species showed significantly more cover relative to the Control treatments. Goats gained weight at rates higher than comparable data sets from other regions of the country. FAMACHA anemia scores, as an indication of gastrointestinal nematode infection, were not influenced by treatments. Goat dietary selections were dominated by woody species (84% of the diet), followed by forbs (12%), and graminoids (3%). Goats selected more woody species than would be predicted on availability alone, and selected less forb and graminoid forages than was available. Goats spent the majority of their time eating woody species consisting of *Cornus racemosa* (13.5%), *Zanthoxylum americanum* (7.23%), *Tilia americana* (6.44%), *Rubus occidentalis* (6.16%), *Prunus virginiana* (6.02%), and *Ulmus americana* (5.13%) for the average goat diet. This study was designed to avoid significant damage if the goat browsing Heavy treatment turned out to be harmful to the biotic and abiotic factions of the YLWA oak savanna site. Heavily browsed treatments made improvements in site openness during the 3-year study period. We recommend conducting this study for a longer period, and to increase the goat stocking level to remove nearly all of the browse within goat reach during each rotation.

TABLE OF CONTENTS

List of Figures

List of Tables

APPENDIX A

APPENDIX B

APPENDIX C

APPENDIX D

Acknowledgements

I would like to thank my advisor, John Harrington, the Landscape Architecture Department and the Agroecology Department for their support and advice throughout the research process. Also, I appreciate the ongoing support of my PhD advisor, Dr. Dan Schaefer as I finished the analysis and writing process.

Thank you to Dr Richard Cates and Dr. Steven Ventura for serving on my committee and for their input and feedback.

Funding for this research was generously provided by a grant from Wisconsin Grazing Lands Conservation Initiative (GLCI), a graduate student grant from the North Central Region Sustainable Agriculture Research and Education (NCR-SARE) program, a good husbandry grant to Cherrie Nolden from Animal Welfare Approved for electronet fences, a grant from the UW-Madison Center for Integrated Agricultural Systems (CIAS), a mini grant from the UW-Madison Agroecology Program, and RAships from the Landscape Architecture Department and the Agroecology Program.

The summer field work was greatly aided by Keefe Keeley, Rebecca Dymzarov and Lee Nolden.

The initial research protocol was set up by Bruce Folley, John Harrington, Jesse Bennet.

Contributions of prior year protocols, helpful hints, data and preliminary analyses by the two prior graduate students on this project, Julia Ela and Katherine Baumann, were woven into this thesis to show the full results of the multi-year study design.

Goat herds were contributed by Driftless Land Stewardship, Vegetation Solutions, and 1dr Acres Farm. Without the privately owned goats, this research would not have been possible. Grant funding covered costs of hiring the first two herds and the third herd was provided and managed without financial compensation by 1dr Acres Farm.

The willingness of Bruce Folley with the Wisconsin DNR to embrace testing browsing goats as a brush management tool at the Yellowstone Lake Wildlife Area, and providing mowed trails between blocks and treatments, plus the bulk water wagon and pump, was critical in conducting this research and is very much appreciated given the biases against livestock and goats in particular.

Thank you to Peter Crump and Nick Kueller for their assistance with the statistical analyses.

Thank you to my prior husband, Lee Nolden, and my current husband, Allen Philo, for their assistance with research project tasks and being supportive of me through the process.

CHAPTER 1:

Introduction

Oak Openings

Oak openings, also known as oak savannas, consist of plant communities with a canopy of oak trees (*Quercus* spp.) and an understory of native prairie graminoid and forb community (Curtis, 1959). Savanna communities are found on every continent (Werner et al., 1990), mostly in temperate climates (Anderson and Bowles, 1999; Will-Wolf and Stearns 1999), and in Wisconsin they are found along the prairie-forest ecotone or tension zone between open prairie to the west and woodland to the east (Cochrane and Iltis, 2000). A common trait of savanna communities is the lack of well-developed brush and midstory layers (Curtis, 1959; Taft 1997).

More than 2,000,000 hectares in Wisconsin (Compton et al., 2003) and over 20,000,000 hectares in the Upper Midwest (Savanna Oak Foundation, n.d.) were covered by high quality oak savanna in the 1800s, but now, in 2019, less than 0.01% remain (Curtis, 1959; Compton et al., 2003). Oak savannas are categorized as critically threatened due to post-European settlement clearing for conversion to farmland, suppression of fire, overgrazing and then subsequent lack of grazing (Compton et al., 2003). In the absence of fire and grazing, the savanna understory fills with shade-tolerant brush, vine, bramble and tree species, reducing light levels at the ground layer and changing the plant community composition to more woody, aggressive, or non-native species (Nuzzo, 1986; Henderson & Epstein, 1995; Nowacki and Abrams, 2008) and decreasing diversity and complexity of the community (Solecki, 1997). Species defined as aggressive in this thesis are those commonly identified as increasers in unmanaged savanna systems by restorationists and are listed in Table 6 of Appendix A. The majority of oak savanna remnants in Wisconsin are located on unfarmable hillsides, many of which are on private land (WDNR, 2012) and are degraded (Harrington, personal communication). State-owned parcels tend to be in better condition than privately-owned parcels due to budgeted conservation targeted management (Harrington, personal communication). Many poorer quality remnants are restorable to the original structure and to moderate quality, but restoration methods are often time intensive with prohibitive costs (WDNR, 2012). Due to these costs, very few are restored.

Management Options for Unwanted Vegetation

Fire is touted as the most effective restoration tool by restorationists (Sheuyange et al., 2005; Staffen, 2010), but private landowners often perceive fire as a high liability with few economic benefits (Henderson, 1995, Harrington and Kathol, 2009). In addition, fire can be ineffective in penetrating very dense vegetation with damp fuels (Nowacki and Abrams, 2008; Harrington and Kathol, 2009), which is the common condition of brush-invaded oak systems (Haney and Apfelbaum, 1995; Compton et al, 2003). In similar mesic prairie systems, burning can result in the aboveground expansion of clonal brush species and fails to kill well-established brush (McCarron and Knapp, 2003; Heisler et al., 2004). Prescribed fire can only be conducted once in a year, or perhaps twice if sufficient fuel grows back to carry the fire, and the Wisconsin DNR estimates that it may take 15 years of consistent annual burning to eliminate or significantly reduce brush in savanna communities (Staffen, 2010). Prescribed fire has a high liability potential, and private landowners often lack the training or don't have sufficient personnel available to conduct an effective burn (Henderson, 1995). Weather and site conditions also limit the application and effectiveness of fire (Anderson and Bowles, 1999; Will-Wolf and Stearns, 1999; Marcora et al., 2018; Daryanto, et al., 2019).

Other common methods, such as mechanical removal and herbicides, are limited by cost, slope, weather and potential damage to the herbaceous layer (Magadlela et al., 1995; Arborist Site, 2009; Heavy Equipment Forums, 2009; Staffen 2010). Forestry mowing can cause compaction and disturbance of soils, is costly, and is inadvisable when the site is wet or icy (Magadlela et al., 1995). Additionally, mechanical treatment of brush without chemical follow-up has low effectiveness and high cost (McCarron and Knapp, 2003; Heisler et al., 2004). Chemical application is best conducted at certain times of the target plant's growth stage and chemical effectiveness is often weather-dependent (Kochenderfer et al., 2012; WDNR, 2012).

In ecosystems dependent upon fire, additional tools are often needed as substitutes in situations where fire cannot be employed, as an initial treatment to allow fire in the future or as a more selective treatment between prescribed burns (Magadlela et al., 1995; McCarron and Knapp, 2003; Heisler et al., 2004). Rotationally browsed livestock have the potential to fill this supplemental role since they can be applied any time throughout a growing season, multiple times per season, and independently of weather (Hart, 2006; Papanastasis, 2009; Harrington and Kathol, 2009; Hart, 2012).

Brush Response to Disturbance

Root buds are stimulated by defoliation and stem removal. A single application of defoliation, cutting or burning results in an increase in plant biomass due to vegetative regeneration from root and stem buds (Bory et al., 1991). Repeated defoliations drain the underground carbohydrate root reserve over time and can kill the plant (Ratajczak et al., 2011; Hart, 2012), but to do so requires annual treatments over many years, and often these treatments are not maintained (Daryanto et al., 2019). Defoliation or girdling without removal of the apical bud results in less suckering (Smith et al., 1972; Schier and Smith, 1979), but removal of twig tips and girdling stimulates root buds to produce sprouts (Willard and McKell, 1978).

Historical Brush Management

Native herbivores such as elk, bison and white-tailed deer would have historically browsed and grazed the Midwestern oak savannas and selected different forages (Romme et al. 2005, Towne et al. 2005, Urbanek et al. 2012). Their populations would have been managed by wolves and other top predators throughout the time of European settlement (Chavez et al., 2005). As those wild ungulate species were replaced by domestic herbivores, the plant community shifted, and soil erosion increased (Trimble and Mendel, 1995). Introduced weedy exotic species such as Kentucky bluegrass (*Poa pratensis* L.) was intentionally sown by settlers to improve the forage quality for their livestock (O'Connor, 2006). European settlers also introduced plants for other agricultural, culinary, ornamental and medicinal purposes (Mack, 2003), and many of those species were dispersed to natural areas such as oak savannas, where they continue to affect the ecological function of those systems today. The ornamental shrubs are a particularly problematic group of Eurasian origin that were originally planted as ornamental hedges (Mack, 2003), or for wildlife value (O'Connor, 2006). Some of those species include common buckthorn (*Rhamnus cathartica* L.), honeysuckles (*Lonicera* spp.), autumn olive (*Elaeagnus umbellata* Thunb.) and multiflora rose (*Rosa multiflora* Murray). Frugiverous birds readily consume and disperse the seeds of these species (Knight et al. 2007, Gleditsch and Carlo 2011), and sometimes preferentially over native fruiting shrubs fruits (Lafleur et al. 2007). Open grown oaks are commonly used perches for these birds, where the fruits and seeds are dropped, thus facilitating invasion by these exotic shrubs into Midwestern savannas (O'Connor 2006). Knight et al. (2007) suggests that other traits such as rapid growth, allelopathy, a tolerance of a wide range of environmental conditions, high germination rates, and success in disturbed habitats may have exacerbated this plant invasion in Midwestern savannas. Apfelbaum and Haney (1991) showed that these savanna remnants are particularly vulnerable to invasion given the high edge to size ratio of many remnants. Today's Midwestern oak savannas are populated by many of these species (Packard 1988, Bowles and McBride 1998, O'Connor 2006, Hedtcke et al. 2009, Abella 2010). These species, along with environmental condition shifts, have altered the ecological processes that are characteristic of, and critical to the persistence of oak savannas.

Goat Impacts on Brush

Goats will not provide the rapid control or eradication of vegetation that can be achieved with herbicides, but they can provide repeated defoliations that will kill or weaken woody plants over time (Griffin et al., 2005; Hart, 2006; Schafer, 2013). Besides foliage removal, goats strip bark, which can girdle and cause top-kill or complete death (Hart, 2012). The suckers that arise from a girdled tree are readily consumed by goats (Papachristou et al., 2005; USDA-FS, 2012). Some annual plants can be controlled by goats consuming the seeding stalks to reduce accumulation of the seed soil bank over time (Hart, 2012; Elias and Tischew, 2016).

When vegetation reaches over 2 meters, goats will have a hard time reaching the branches to defoliate (Lyons and Hanselka, 2001; Hart, 2005, Elias and Tischew, 2016). According to Hart (2006) taller brush will either take an extended period of goat browsing to control the brush, or it will need to be chainsawed/mowed and followed by goats to control the suckers and newly germinated seeds.

Targeted browsing of brush and other aggressive species involves knowing each species' weaknesses. Often, when a plant is flowering, it will have extended the majority of its energy for the year, and causing injury to the plant at this time can reduce the plant's vigor and survival (McIver et al., 2009; Beeden 2010; WDNR, 2012). Hart (2006) recommends fully defoliating the brush with goat browsing early in the spring, multiple times throughout the growing season with less than 8 weeks between defoliations, and again late in the fall. This will provide maximum stress to the brush.

Rotational Browsing

Intensive rotational grazing is a highly managed method in which livestock are grazed at high stocking densities for a short period of time and rotated successively through a series of small paddocks (Barnes et al., 2008). Vegetation is then allowed to recover during a resting period before livestock are rotated through the same paddocks again in order to avoid environmental impacts often arising from continuous grazing (Bailey and Brown, 2011). Anderson (1998) and Barnes et al. (2008) stress that managed grazing is different than the continuous grazing that contributed to the decline of oak savanna in the past.

Publications discussing livestock for prescriptive grazing are found as far back as the 1930s (Mosley, 1996), but the use for managing unwanted species is relatively new (Johnston and Peake 1960, Sharrow et al. 1989, Hedtke et al. 2009, Kleppel and LaBarge 2011), and many current land managers in the Upper Midwest are skeptical of the utility of livestock for aggressive vegetation control because they have seen an array of environmental problems caused by unmanaged grazing (Harrington, 1998; Henderson, 1998; Vavra, 2005; Peacock and Sherman, 2010; P. Zedler, personal communication, February 19, 2013). Continuous and unmanaged grazing practices have been destructive to ecosystems in the U.S. and globally, regardless of livestock species (Auclair, 1976; Fleischner, 1994). Environmental problems caused by unmanaged grazing include soil compaction, erosion and loss of native vegetation (Fleischner, 1994). Unmanaged grazing can shift grassland to woody species (Walker, 1993). Other studies have demonstrated that these impacts can be controlled when grazing is carefully managed (Papanastasis, 2009; Teague et al., 2011; Garcia et al., 2012).

Intensive rotational grazing has been explored as a vegetation management tool in the U.S. and globally, without the damage associated with continuous or unmanaged grazing

(Walker et al., 2006). Intensive, short-duration rotational browsing, where livestock are regularly rotated between paddocks, has been found to reduce brush cover while enhancing livestock production (Compton et al., 2003; Campbell and Taylor, 2006). Rotational grazing of Scottish Highland cattle, a breed with a high proportion browse diet selection, has been studied as an alternative means of brush removal in oak savannas in Wisconsin (Harrington and Kathol, 2009). This breed was effective at reducing above-ground growth for specific brush species and was observed feeding in areas where brush was too dense for fire to penetrate (Compton, et al., 2003).

Despite successes of brush removal in Wisconsin with Scottish Highland cattle, the logistics of frequent transportation of such large animals required for a short duration rotational grazing regime was an obstacle (Harrington and Kathol, 2009), plus cattle need to have grassy forages available to them to provide a complete diet rather than subsisting wholly on woody species forage like goats (Aharon et al., 2007; El Aich et al, 2007; Osoro et al, 2013). Domestic goats (*Capra aegagrus hircus*) are easier to transport (personal experience), and they have reportedly been used for vegetation management for at least 100 years in the USA (Hart, 2012).

Goat Attributes for Browsing

Goats have several characteristics that suit them well to small brush management. Their most unique attribute is their high dietary selection for browse over forbs and grasses. Goats readily eat thorny plants and have higher browse diets than the Scottish Highland cattle (Gordon, 1989), with a greater tolerance of tannins than cattle or sheep, and goats rarely bloat (McMahon et al., 2000; Hart, 2006). According to Hart (2005), goats are a low-input species of livestock, require a very small investment for start-up, have inexpensive maintenance, and require only a moderate level of labor for animal management. Goats are smaller and more mobile than Scottish Highland Cattle (Harrington and Kathol, 2009; Ela, 2012), with nimble lips and a propensity to browse while standing on their hind legs (Haenlein et al, 1992). Goats will climb brush and trees to reach desirable vegetation (El Aich et al., 2007). Goats consume and digest seeds, reducing the viability and number of aggressive plant seeds (Pierce, 1987; Launchbaugh, 2006), and they strip the bark off thin-barked trees, resulting in girdling and plant death (Rahmann, 2000; Holst et al., 2004; Fajemisin et al., 2007). The nutrients that are tied up in woody vegetation are made available to the ecosystem through goat digestion and deposition in the form of urine and feces (Severson and Debano, 1991; Hart, 2006;). Goats are adapted to arid environments, thus they exhibit small size, low metabolic requirements and efficient use of water (Malan, 2000; Alexandre & Mandonnet, 2005).

Review of Goat Browsing

Application of goats for brush control in rotational browsing systems is a relatively new concept in the Upper Midwest, but goats have unique dietary preferences and approaches to vegetation control that make them a feasible alternative tool to chemical or mechanical control of aggressive vegetation (Distel and Provenza, 1991). Goat browsing has been studied for woody fuel reduction, aggressive species management, pasture maintenance and ecosystem restoration in structurally similar ecosystems in the U.S. and globally (Strang, 1973; Batten, 1979; Tsiouvaras et al., 1989; Severson and Debano, 1991;

Perevolotsky and Haimov, 1992; Torpy et al., 1993; Popay and Field, 1996; Haumann, 1999; Luginbuhl et al., 1999; Valderrábano and Torrano, 2000; Holst et al., 2004; Smart et al., 2006; Aharon et al., 2007; Celaya et al., 2010; Ascoli et al., 2013; Rathfon et al., 2014; Elias and Tischew, 2016). Reduction of the brush canopy in Midwestern grassland ecosystems has resulted in more light at the herbaceous groundlayer and enhanced availability of habitat for the growth of desirable sun-tolerant herbaceous species, particularly warm-season grasses (Heisler et al., 2004; Nowacki and Abrams, 2008; McGranahan, 2011).

Dietary Selection Discrimination

Although goats are widely thought to eat anything, including tin cans, they are quite particular in their dietary preferences (Papachristou, et al., 2005). Hart (2006) reports that the greatest factor influencing the food consumed by a goat is that which they have learned to eat from their mothers, with the second most important factor being the plant community that they consumed in their first year of life. Dietary preferences change with time of year and location, as the plant chemicals change with the weather and season, presumably impacting palatability (Papachristou and Nastis, 1993b; Hart, 2006). Browse preference also changes with availability, where goats alone preferred brush as 50% of their diet, but goats browsed after sheep had eaten the grass and forbs in a paddock selected brush as 70-90% of their diet (Sidahmed et al., 1981). Availability of nutritious alternatives, period of grazing and stocking rate also influence diet selection (Papachristou and Nastis, 1993a).

Unpublished data from a research project on land belonging to the USDA Dairy Forage Research Center land at the Badger Army Ammunition Plant (BAAP) in Prairie du Sac, WI (Nolden, unpublished data) indicates that goats readily defoliate and strip bark on autumn olive (*Elaeagnus umbellata*), buckthorn (*Rhamnus cathartica*), prickly ash (*Zanthoxylum americanum*), box elder (*Acer negundo*), elderberry (*Sambucus canadensis*), mulberry (*Morus rubra*), hackberry (*Celtis occidentalis*), hophornbeam (*Ostrya virginiana*), young elm (*Ulmus* spp.) and young honeysuckle (*Lonicera tartarica*, *L. morrowii*, *L.* x bella). Woody species that are readily defoliated and the tips eaten include blackberry (*Rubus allegheniensis*), raspberry (*Rubus occidentalis*), gooseberry (*Ribes cynosbati*), multiflora rose (*Rosa multiflora*) and poison ivy (*Toxicodendron radicans*). Goats also readily eat spotted knapweed (*Centaurea biebersteinii*) and leafy spurge (*Euphorbia esula*) (Nolden, unpublished data). Long-term browsing trials in Oklahoma found similar results, with the addition of 3 to 8 years to kill the plants (Gipson, 2005). Blackberries were controlled in 3 years, eastern redcedar (*Juniperus virginiana*) in 2-5 years, honey locust (*Gleditsia triacanthos*) within 1-2 years, rose species (*Rosa* spp.) took 3 years, dogwoods in 2-3 years, wild plum (*Prunus* spp.) in 3 years, sumac (*Rhus* spp.) in 2-3. Gipson (2005) and Nolden (unpublished data) noted that few herbaceous species are not eaten by goats, with common mullein (*Verbascum thapsus*) being the most notably avoided plant. Garcia et al. (2012) list plant species that are often considered weed species, which are palatable to goats.

Time of year, stage of plant maturity, and region affects consumption of browse by goats (Mitchell, 1996). Forage qualities may influence the dietary preferences of goats. Many of the aggressive plants that goats consume contain medicinal properties due to secondary plant compounds that have been reported by a number of authors (Sheaffer et al., 1990; Barnhart 1994; Makkar et al., 2009; Brunetti and Jodarski, 2011). Brunetti and Jodarski (2011) also showed that many of the plants that goats prefer contain higher levels of protein than the common forages of alfalfa (*Medicago sativa*), orchardgrass (*Dactylis glomerata* L.), or bromegrass (*Bromus inermis*).

Factors Affecting Brush Control by Goats

Perryman et al. (1995) believe that the essence of plant damage by livestock does not lie as much in the timing of grazing applications as in the duration and intensity, however, Bryan, (1994) observed that timing did have an influence on plant damage, with spring browsing producing a greater negative impact on brush than browsing after August in West Virginia. Repeated brush defoliation depletes stored energy reserves, weakening and or killing brush (Gipson, 2005). Previous studies suggest that brushy plants must be browsed as least twice in a single growing season in order for the impact to be long-term (Davis et al. 1975, Hart 2006), so frequency is also an important factor. Stripping of bark by goats will kill woody vegetation greater than 2 meters tall (Mitchell, 1996).

Examples of Goat Browsing Effectiveness

Data from the Upper Midwest on the length of time or amount of goat browsing that is required to kill brush using goats is not published. One short-term study (Rathfon et al., 2014) was conducted in Indiana, rotating 6.5 and 19.4 goats per ha (16 and 48 goats per acre) once in spring or twice with half the goat numbers in fall, achieving full defoliation prior to rotating, over the course of a single year, to test effects of goat browsing intensity and frequency on aggressive woody and herbaceous plant species. Their instantaneous stocking density was 12 or 4 goats per 0.101 ha (¼ ac) for the first browsing and 6 or 2 goats per 0.101 ha (¼ ac) for the second browsing. One woody species, spicebush (*Lindera benzoin*), showed a significant decrease in height in the heavily one-time browsed treatment (HS1), and in the lightly twice-browsed treatment (LS2), relative to control ($Pr > F = 0.035$, $\alpha = 0.05$), comparing pre-browse height in May with brush height the following May. Manual cutting and herbicide provided the same effect as HS1 and LS2 relative to the control treatment. Herbaceous species diversity and distribution didn't change over the single year of the study between the treatments ($Pr > F = 0.3078$, $\alpha = 0.05$). Herbaceous species cover reduced in all treatments due to drought, and there was a nearly significant decrease in the heavily browsed treatments relative to control, reducing cover by 24% (HS1) and 28% (HS2) ($Pr > F = 0.0532$, $\alpha = 0.05$). Goat stocking rate did not affect aggressive woody or aggressive herbaceous species cover or height in the first year of goat browsing. The authors concluded that trends suggested the goats could have a beneficial effect but more years of browsing would be needed to assess impacts and evaluate the effectiveness of goats for brush management.

In steep West Virginia terrain, an early-season stocking rate of 3-4 adult goats per hectare (8-10 goats per acre) were applied to land covered 45% by multiflora rose (Bryan, 1994). Goats browsing reduced the brush cover to 15% in one season, whereas it took sheep three seasons to accomplish the same. The researchers noted seasonal effects, where browsing early in the year was effective, but browsing after August first was deemed to produce negligible impacts on the multiflora rose. It took the goats 5 years of repeated rotational browsing to kill 98% of the multiflora rose at the site.

Mitchell (1996) conducted research on goat stocking rates in Oklahoma for control of aggressive brush. He recommends 2.471 goats per ha per % brush cover (1goat/ac/% brush cover) as a season-long stocking rate for brush control. By applying 3.71 goats per ha on a 13 ha parcel (1.5 goats per acre on 32 acres) with 43% brush cover, goats cleared all of the above ground browse within two seasons. Applying the same goat stocking rate on a 9.7 ha (24 ac) parcel with 62% brush cover took more than two seasons to clear the brush.

Mitchell (1996) found that rotating goats is more effective than set-stocking for brush control in Oklahoma. When in a dense group that is rotationally browsed, goats provided more uniform brush removal and were healthier due to the diverse diet consumed by the animals. Management can be adaptive, with the animals being moved when the desired impact is obtained in a particular paddock. Mitchell noted that the percent of brush that recovers is reduced with each browsing event.

Grazing has been shown to affect leaf litter, usually reducing its depth due to trampling (Davis et al., 1975; Decker, 2018). Litter reduction also occurs due to the loss of above ground brush and herbaceous material from browsing, leaving less plant matter to fall to the ground (Tsiouvaras et al., 1989; Fuhlendorf et al., 1997). Leaf litter impacts seed germination as well as soil stability, compaction, organic matter, and moisture (Xiong and Nilsson, 1999). Less litter provides greater likelihood of direct seed contact with the soil, but too little litter can result in soil erosion and quicker desiccation as litter protects soil from both from direct water drops and sunlight (Stavi et al., 2017). Harrington et al. (unpublished data) found that litter depth decreased in the heavily browsed paddocks from an average of 15.7 mm to 11.6 mm in 2011 at the YLWA.

Repeated rotational browsing by any type of livestock has the potential to cause compaction of soils, which in turn can constrain plant root growth and therefore nutrient acquisition (Brock, 1988). Harrington et al. (unpublished data 2011; Harrington and Kathol, 2009) found that soil did not become significantly more compacted under rotational grazing with either cattle or goats.

Goat Performance on Brush Diets

In order to consider the use of goats as a tool for ecological restoration, the animals need to demonstrate, at a minimum, a maintenance of health when being browsed on the aggressive brush. Metrics for health in goats include the rate of body weight gain of kids, body weight maintenance in adult goats, maintenance of body condition, and management of internal parasites. Very little research exists on the performance of goats in oak ecosystem brush control applications.

The average daily gain results from goat browsing at the BAAP (Nolden, unpublished data) averaged 91 grams per day (g/d) (0.20 lb/d) with no supplemental energy or protein, just *ad libitum* salt/mineral supplement. A full-blood Boer goat, which is bred to gain weight fast on high energy grain supplements, can gain from 227 to 318 g/d (0.5 to0.7 lb/d) when fed ad libitum grain (Barry and Godke, 1978). Goats at the YLWA site did not receive supplemental energy or protein.

Average rates of gain in the Western Maryland University Pasture-based Meat Goat Performance Test were 57.0 g/d (0.125 lbs/d) in 2011, 62.1 g/d (0.137 lb/d) in 2012, and 33.2 g/d (0.073 lb/d) in 2013, with the 2013 winning goat gaining 86.2 g/d (0.190 lb/d) (Schoenian, 2013). This test most closely matches the protocol we used at the YLWA of no grain, forage only, but the Maryland test was conducted on a tame grass/legume pasture rather than in a brushy paddock. The next most comparable data would be from the Oklahoma Forage-based Buck Test, where from 2007-2011 the average daily gain was 63 g/d (0.14 lb/d) (Penick, 2012; Langston University, 2016). These results are harder to compare to gains anticipated from goats grazed in the Upper Midwest since the Oklahoma protocol frequently included a protein supplement of DDGs. According to the Oklahoma researchers, an average daily gain in the range of 45.4 to 181.4 g/d (0.10 to 0.40 lbs/d) is considered excellent for meat goat kid growth on pasture (Langston University, 2016). Average rates of gain in the Oklahoma Forage-based Buck Test were 103.31 g/d (0.228 lbs/d) in 2011, 95.41 g/d (0.210 lb/d) in 2012, and 128.28 g/d (0.283 lb/d) in 2013 (Penik, 2012; Howard et al., 2013).

Goats are highly susceptible to gastrointestinal nematode parasites, especially the barberpole worm, *Haemonchus contortus (H. contortus)* (Vatta et al., 2001; Hart, 2006). Infested goats have lower growth rates, markedly reduced reproductive performance, and have higher rates of illness and death (Leite-Browning, 2006). Consequently, *H. contortus* may account for greatly reduced profits in a goat operation. The FAMACHA © anemia scoring system was developed by South African scientists and veterinarians (Malan et al., 2001; Bath et al., 2001; Van Wyk and Bath, 2002) as a low-cost tool to assess clinical anemia by examining the color of the goat's lower eyelids (Figure 1) and comparing it to a color-coded FAMACHA © chart (Kaplan et al., 2004). The chart has five color categories (scores), each corresponding to varying degrees of anemia (Freking, 2017). Score 1 represents a healthy animal (normal reddish eye conjunctivae), while score 5 represents a highly anemic animal (porcelain-white conjunctivae) (Bath et al., 2001). A FAMACHA © score of 1 indicates good packed cell volume (PCV), which is correlated with low *H. contortus* parasite effects on the host (Lewandowski, 2010; SAPPLPP, 2014, Figure 2).

Figure 1. Goat FAMAHCA © scoring. Deep pink inner eyelid color on a goat in Cherrie Nolden's herd, indicating low impact of *H. contortus* parasite infection, which would be given a FAMAHCA © score of 1.

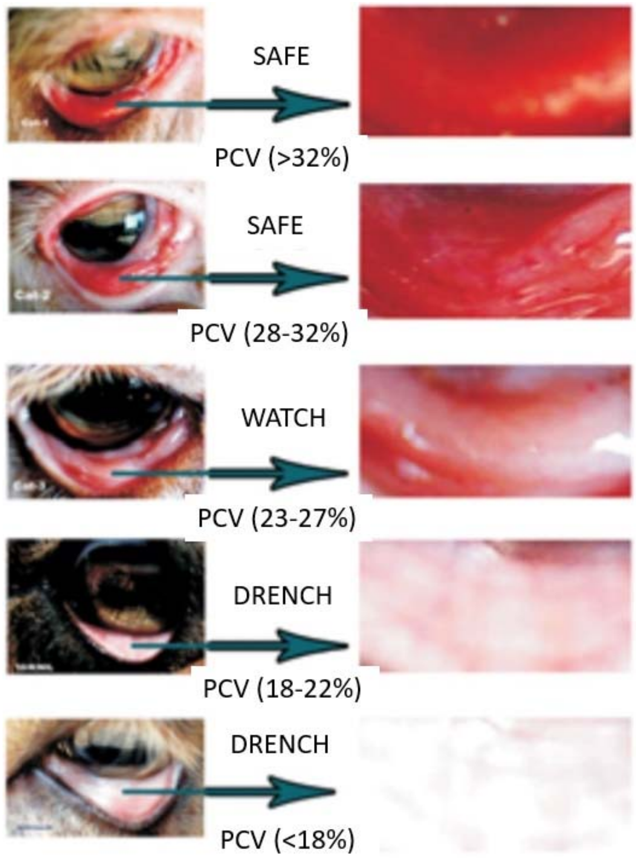


Figure 2. PCV for FAMACHA. Packed cell volume and relative inner eyelid color for FAMACHA © scoring. The top color is a FAMACHA © score of 1 and the bottom color is a FAMACHA © score of 5. Image adapted from Figure 1 of Singh and Swarnkar, 2012.

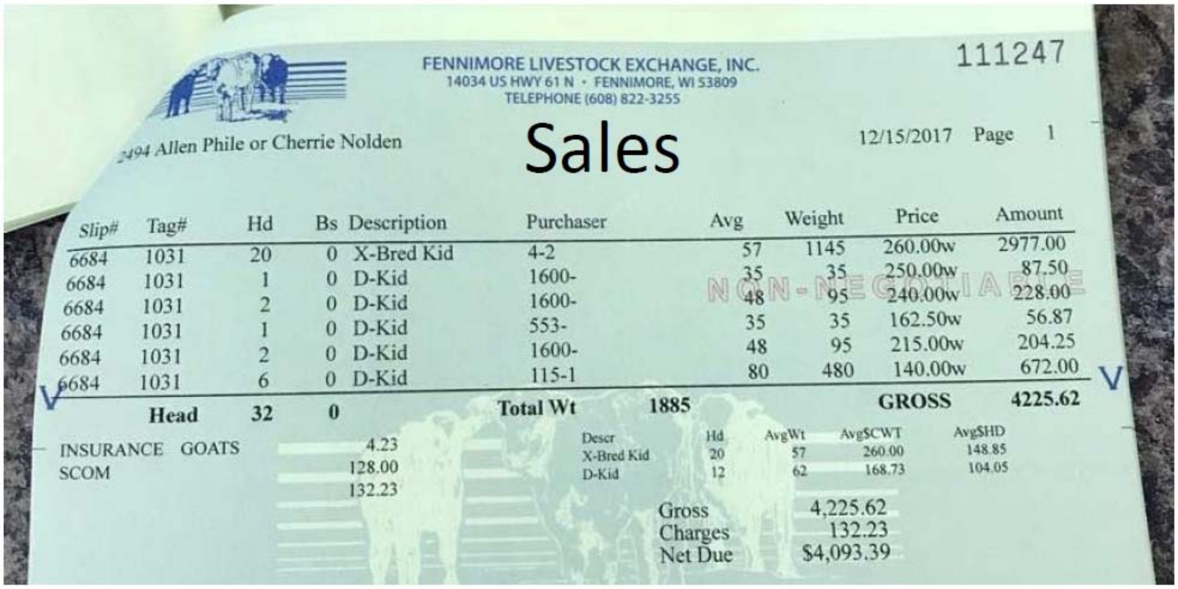
Deworming is recommended at 3 or higher (Kaplan et al., 2004), with acceptable FAMACHA © scores between 1 and 3. Data from BAAP indicated that goats not receiving deworming treatments became more parasitized over the browsing season, but stayed within the acceptable scores (Nolden, unpublished data).

Goat Meat Demand and Opportunities

In addition to the potential conservation advantages, the demand for goat meat in the U.S. is increasing, creating a potential economic incentive to raise goats for meat. By conservative estimates (Solaiman, 2007), there is currently a nearly 730,000-head deficiency in meeting goat meat demands in the United States (Rayer, 2012), the equivalent of a $74.4 million opportunity for farmers selling at average auction prices in 2011. The U.S. imported more than 16,000 metric tons of goat meat in 2012, up 6% from 2011 and up 45% from 2007 (Rayer, 2013). U.S. consumption of goat meat is expected to continue to increase as ethnic groups for whom goat meat is a dietary staple become more prominent, and as health-conscious Americans realize the nutritional value of this type of meat (Solaiman, 2007).

Grain is expensive and not necessary to feed to goats if acceptable rates of gain can be obtained with rotational grazing in brush. Additionally, the meat of grain-free goats is healthier for the consumer since it contains a better ratio of omega 3:omega 6 fatty acids than grain-fed goats (Duckett et al., 1993; Siscovick et al., 1995; Lopez-Bote, 1998; Simopolous and Robinson, 1999).

From an economic perspective, a target daily gain of between 94 and 141 g (0.207-0.311 lbs) would produce a prime-sized market goat for the specialty Christmas market if born on pasture in June in Wisconsin. June is a time of year when kidding on pasture is feasible due to good weather, forage quality meets lactation needs of the does, and the labor requirement is lowest in Wisconsin. The prime market size is 18-27 kg (40-60 lbs) and buyers typically pay between $100-150 per goat for properly conditioned meaty goats of that size range at that time of year (Figure 3). This produces a return per adult doe that can provide a full-time income over feed costs of around $30,000.00 with a herd of 250 does (personal financial evaluation of Cherrie Nolden's meat goat production system, Appendix D).



FENNIMORE LIVESTOCK EXCHANGE, INC.
14034 US HWY 61 N • FENNIMORE, WI 53809
TELEPHONE (608) 822-3255

111247

2494 Allen Phile or Cherrie Nolden

Sales

12/15/2017 Page 1

Slip#	Tag#	Hd	Bs	Description	Purchaser	Avg	Weight	Price	Amount
6684	1031	20	0	X-Bred Kid	4-2	57	1145	260.00w	2977.00
6684	1031	1	0	D-Kid	1600-	35	35	250.00w	87.50
6684	1031	2	0	D-Kid	1600-	48	95	240.00w	228.00
6684	1031	1	0	D-Kid	553-	35	35	162.50w	56.87
6684	1031	2	0	D-Kid	1600-	48	95	215.00w	204.25
6684	1031	6	0	D-Kid	115-1	80	480	140.00w	672.00
	Head	32	0		Total Wt 1885			GROSS	4225.62

NON-NEGOTIABLE

INSURANCE GOATS 4.23
SCOM 128.00
132.23

Descr	Hd	AvgWt	Avg$CWT	Avg$HD
X-Bred Kid	20	57	260.00	148.85
D-Kid	12	62	168.73	104.05

Gross 4,225.62
Charges 132.23
Net Due $4,093.39

Figure 3. Sale slip for browse-raised goats owned and sold by Cherrie Nolden in 2017. Meat breed goat kids (X-Bred Kid) averaging 57 lbs sold for \$2.60/lb, or \$148.20 per goat, at the Fennimore Livestock Exchange Christmas sale in 2017 in Fennimore, Wisconsin. Dairy goat kids (D-Kid) were all lower per pound because they are less valuable as a meat animal. These prices are typical for these types of goats at this time of year.

Barriers to Adoption in this Region

Small farmers in the Upper Midwest are generally unfamiliar with goat management and ecological community restoration but entrepreneurial by nature. If long-term research in the Upper Midwest demonstrates that managed rotational goat browsing can be ecologically beneficial, this would provide opportunities for farmers to take advantage of under-utilized forage land. Farmers could run their current home-based operations while managing goats on neighboring lands, thus diversifying and expanding their production enterprises to create a more resilient farm and rural community. In addition, aspiring farmers could focus a goat production system on land owned by other people, thus lowering the start-up costs and financial barriers to new agricultural enterprises. This trading of goods and services could lead to long-lasting partnerships between production agriculturalists and conservationists or landowners. The partnership would produce a valuable commodity for one and an ecosystem service for the other, potentially fostering a greater sense of community leading to improved quality of life for both parties (Daryanto et al., 2019).

The barriers in the Upper Midwest to use of goats for control of aggressive plant species, lies in the lack of scientific data about the impacts of goat browsing on the plant communities of the Upper Midwest (P. Zedler, personal communication, February 19, 2013). Restorationists in the Upper Midwest question whether brush control techniques used successfully in other parts of the United States and the world will be similar when applied in the Upper Midwest. Since the Upper Midwest is not a traditional goat culture, nor is it common in the Upper Midwest to integrate the more common cattle culture with restoration activities, there has been hesitancy among natural lands managers (P. Zedler, personal communication, February 19, 2013). This may be changing; in recent years, the number of habitat restoration companies that use goats for vegetation management have increased in the Upper Midwest in response to private landowners and land management organizations, such as The Nature Conservancy hiring goat browsing contractors for brush management (Jesse Bennett, pers. communication, August 2018) and The Natural Resources Foundation of Wisconsin funding a project to use goats to control brush at the Riveredge Nature Center in Ozaukee County, Wisconsin (Williamson, 2015). I have helped many new goat browsers get their businesses started, including Allysse and Dan Sorensen's business, The Munch Bunch. On August 20, 2019, Allysse posted "ONE HUNDRED" on her Facebook page

(Figure 4). That day they added their 100th property to the waiting list of people who wanted to hire them for contract goat browsing services. They have much more business than they have goats or time with which to provide services. This is common for goat browsing professionals in the Upper Midwest at this time.

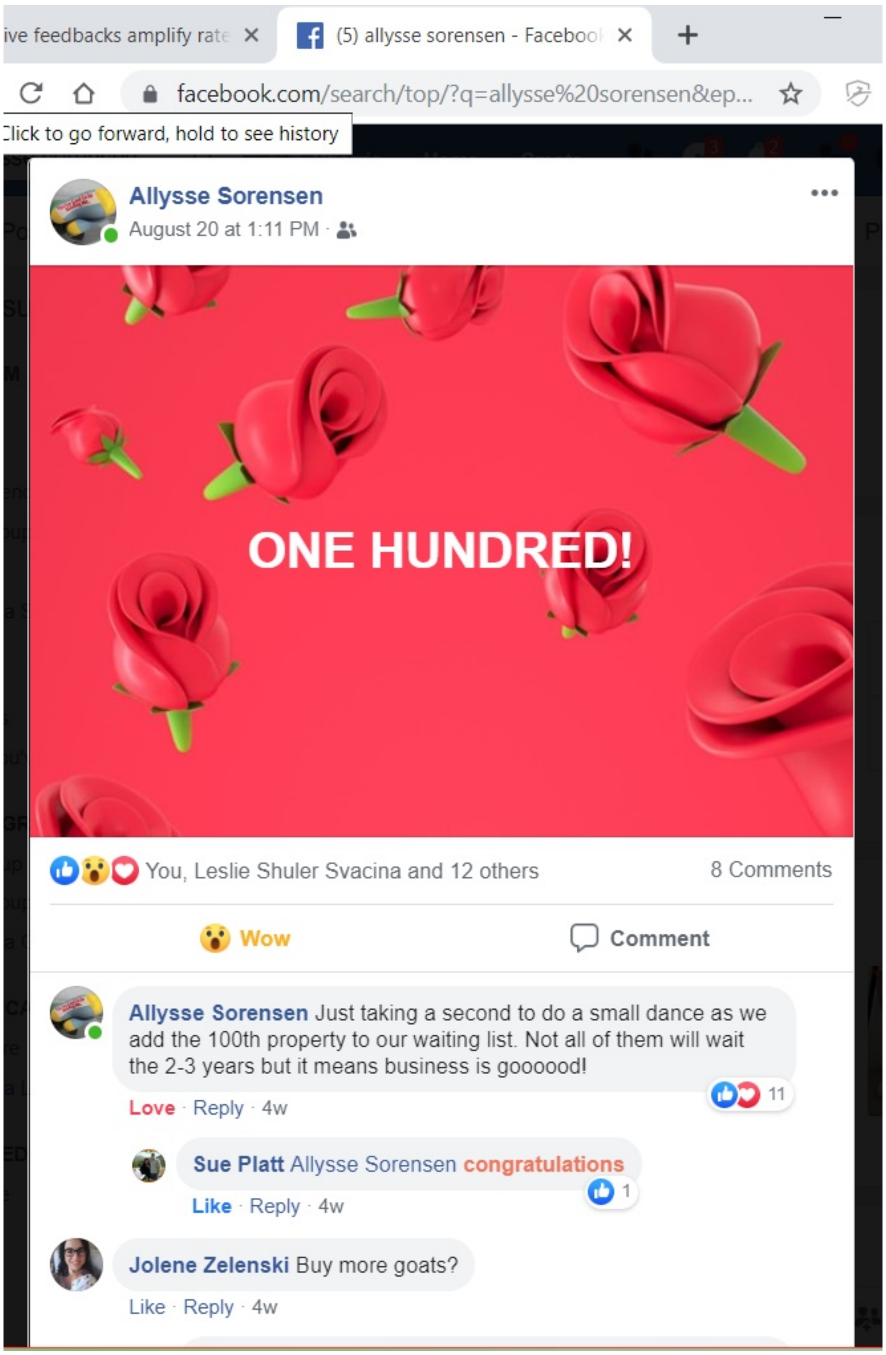


Figure 4. Goat browsing contracting services are in high demand. A Midwestern business that Cherrie Nolden helped get started with providing managed goat browsing services, The Munch Bunch, based near Saint Croix Falls, Wisconsin, and owned and operated by Dan and Allysse Sorensen, posted on their Facebook account that they added their 100th property to the waiting list for their services on August 20, 2019. The demand in the Upper Midwest for goat browsing is strong.

If goats can be shown to assist the management of brush in oak savanna of the Upper Midwest with limited undesired impacts, then Wisconsin is in a unique position for adoption of this brush management practice since (1) the state ranks #1 in the nation for number of dairy goats, and (2) the number of operations with meat goats is growing very quickly as production of small ruminants shifts from the West and SW USA to the Midwest and the Northeast (USDA NASS, 2019; Thomas, 2013). Wisconsin also is able to achieve excellent auction prices for small ruminants due to the state's online Equity Auction and local auctions, while enjoying strong direct market prices from the ethnic centers in Milwaukee, Chicago, Minneapolis, and buyers shipping goats to the East Coast (Thomas, 2013).

HYPOTHESES

Given the above context and previous studies, I tested the following hypotheses:

Brush Density, Stem Count and Height:

H_0: there is no difference in *mean brush density, mean brush stem count, and mean brush height* for the control, light and heavy browsing treatments, H_a: *mean brush density, mean brush stem count, and mean brush height* brush in the control plots are greater than *mean brush density, mean brush stem count, and mean brush height* brush in the treatment plots.

Herbaceous Species Presence/Absence and Relative Cover:

H_0: there is no difference in *mean herbaceous species count and cover, mean sun-loving herbaceous species count* and *cover*, *mean graminoid species count* and *cover* for the control, light and heavy browsing treatments, H_a: *mean herbaceous species count and cover, mean sun-loving herbaceous species count* and *cover*, *mean graminoid species count* and *cover* in the control plots are less than mean herbaceous species count in the treatment plots.

Light Availability at the Ground Layer (LAI), Litter Depth and Soil Compaction:

H_0: there is no difference in *mean LAI, litter depth or soil compaction* for the control, light and heavy browsing treatments, H_a: mean LAI*, litter depth or soil compaction* in the control plots is greater than mean LAI in the treatment plots. Lower LAI equates to greater light reaching the ground layer.

Goat Browse Selection:

H_0: goats consume brush and forbs as a *proportion of their diet* that is equal to the *cover of brush and forbs* in the browsing paddocks, H_a: goats consume brush and forbs as a proportion of their diet that is unequal to the cover of brush and forbs in the browsing paddocks.

Goat Average Daily Gain:

H_0: *mean goat weight* before browsing is equal to mean goat weight after browsing, H_a: mean goat weight before browsing is less than mean goat weight after browsing.

H_0: mean goat *average daily gain* is equal *between each goat class*., H_a: mean goat average daily gain in Kids > Yearlings > Open Does > Nursing Does.

Goat Body Condition Score (BCS) and FAMAHCA © Score Change:

H_0: *mean goat BCS* and *FAMAHCA © score change* is equal *between each goat class*., H_a: mean goat BCS change in Kids > Yearlings > Open Does > Nursing Does.

METHODS

Research Site

The research site is located on a 12-hectare parcel within the Yellowstone Lake Wildlife Area (YLWA) in Lafayette County, Wisconsin. Lafayette County is part of the Driftless Area that covers southwest and western Wisconsin, with the YLWA site located in the Southwest Savanna region.

Sickley et al. (n.d.) described the 1930's presettlement vegetation of this region as a mix of prairie and deciduous hardwood forest with predominant tree species including bur oak (*Quercus macrocarpa)* and white oak (*Q. alba)* with some shagbark hickory (*Carya ovata)* and red oak (*Q. rubra)*. The study site is located on the steep slope between a ridge top and valley. Slopes on the site range from approximately 12% to 30% with the USDA soil survey showing a band of thin rocky soils mid- slope (NRCS, 2011). Bedrock in the area is near the soil surface and is part of the St. Peter formation, composed of sandstone with some limestone and shale (Mudrey et al., 1982).

Bruce Folley is the Wisconsin DNR wildlife biologist who managed the YLWA since 1997. He recounted that the DNR acquired the parcel of land containing the study site in 1989, from a beef grazier. The land, at the time of purchase, was in poor condition due to being severely overgrazed, even though grazing activities had ceased some time before the purchase. The first habitat management activity at the site was a 2008 logging that selectively thinned the oak woodland to a 30% oak canopy, and a forestry mowing that same year (Ela, 2012).

The existing vegetation community is similar to many degraded oak savanna remnants. In the absence of fire and historical browsing pressures, the canopy filled in with mesic species such as American elm (*Ulmus americana)* and American basswood (*Tilia americana)* along with numerous brush species that shaded the forb and graminoid community. The 2008 logging of the site selectively targeted individuals of mesic species leaving a canopy composed of 54% *Q. alba* and 14% *Q. macrocarpa* individuals. *Q. rubra*, *C. ovata*, black walnut *(Juglans nigra)*, and *U. americana* were also present. The anticipated result of the 2008 logging was successional invasion of woody growth, particularly common prickly ash, gray dogwood, honeysuckle (*Lonicera* x *bella)*, quaking aspen (*Populus tremuloides)* raspberry (*Rubus* spp.) and blackberry (*Rubus allegheniensis)*.

The majority of the oak species have an upright growth form, suggesting these grew in a semi-closed setting that is now indicative of an oak woodland. A few oaks occur on the site's south- and southwest-west facing slopes with the widespread horizontal crown structure commonly found in an open, savanna-type ecosystem. There are also several stumps of oaks larger than those currently standing that were logged and may have been open grown.

Indicator plant species of an open oak savanna existed on the site pre-treatment and included: culver's root (*Veronicastrum virginica)*, golden alexanders (*Zizia aurea)*, New Jersey tea (*Ceanothus americanus)*, skyblue aster (*Symphyotrichum oolentangiense)*, New

England aster (*Symphyotrichum novae-angliae)*, paleleaf woodland sunflower (*Helianthus strumosus)*, shooting star (*Dodecatheon meadia)*, yellow-pimpernel (*Taenidia integerrima)*, naked-flowered tick trefoil (*Desmodium nudiflorum)*, and American hogpeanut (*Amphicarpaea bracteata)*.

Experimental Design

In 2011, a randomized complete block design (RCBD) with 5 replicates were located within the 12-hectare site. Each 1.5-hectare block was divided into three 100-meter by 50-meter paddocks (0.5 hectares). Paddocks were positioned mid-slope in such a way that the steepest part of the slope occurred in the center of every paddock. Each paddock was randomly assigned a goat browsing treatment: lightly browsed or heavily browsed or a control (no browsing). Paddocks were divided in half across goat browsing treatments with a split plot treatment of interseeding. One half of each paddock was randomly assigned and broadcasted with a native seed mix while the other half received no treatment. As interseeding was anticipated to affect goat browse selection discrimination at some time in the future, goats were fenced within each half paddock. All block units were buffered with a 1.5-meter mowed swath. A typical replicate block is shown in Figure 5.

The five blocks were positioned so that treatment and control paddocks were oriented up and down the hill, parallel to the slope and each individual block was located to face a single aspect. A site map showing the layout of the replicate blocks can be found in Figure 6. Block A faces west-south-west (250 degrees from north), B faces south-south-east (160 degrees), C faces approximately east (100 degrees, D faces west (270 degrees), and block E faces southwest (220 degrees). The goat research blocks were to the east and slightly south of prior research that considered the impacts of Scottish Highland Cattle for brush control in savannas (Harrington and Kathol, 2009, Figure 7).

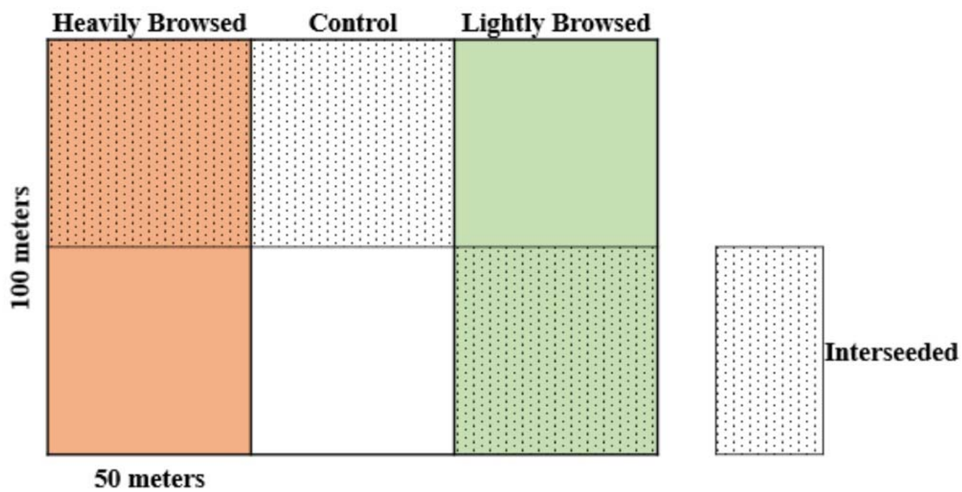


Figure 5: Example experimental unit. An example of an experimental replicate with randomly assigned Lightly and Heavily browsed treatments and control paddocks. Half of each paddock was randomly assigned to be interseeded.

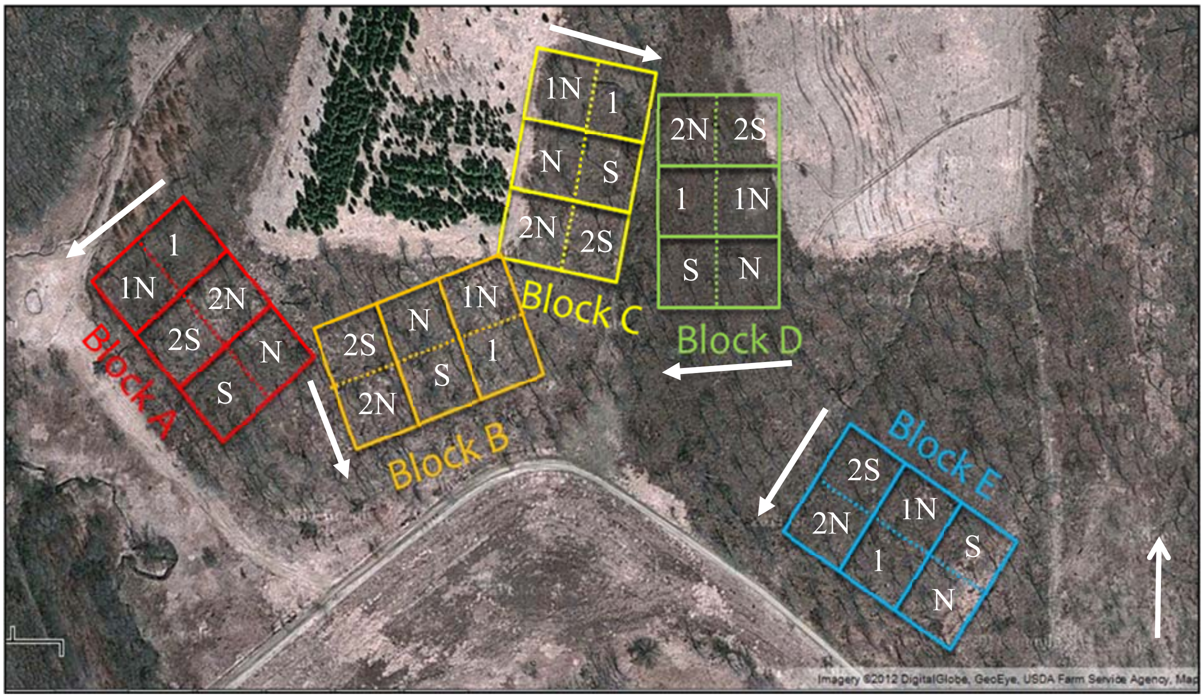


Figure 6: Randomized complete block with split plot design. Five experimental units were arranged along a ridge of variable aspect such that each block faced a single direction with paddocks oriented from top to bottom of the slope. Heavily browsed treatments (2) removed 90% of the vegetation with goat browsing, whereas lightly browsed treatments (1) removed 50% of vegetation. Control and browsed treatment paddocks were divided in half for a split plot treatment and assigned seeding (S) or no seeding (N) (Google Maps, 2012). Arrows indicate downslope direction.

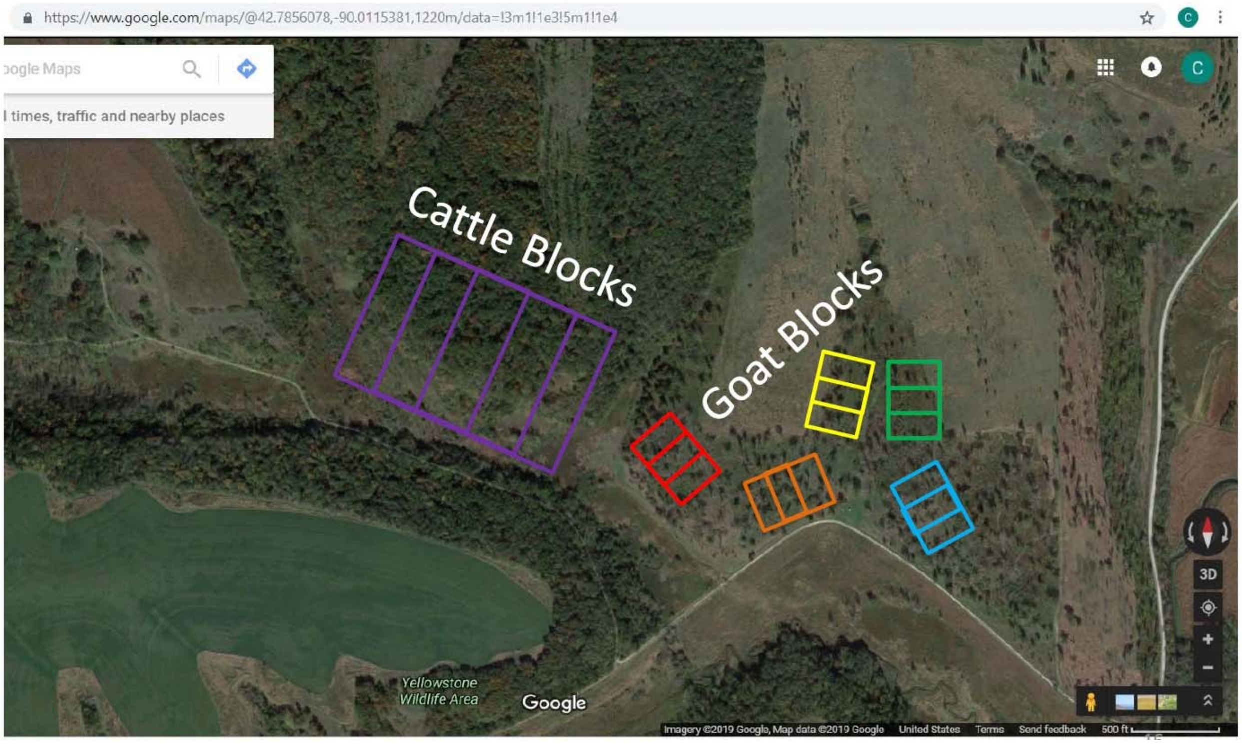


Figure 7. Research blocks relative to cattle research. Location of goat browsing research blocks, relative to Scottish highland cattle research blocks from Harrington and Kathol (2009) research.

The initial stocking rate in 2011 and 2012 was determined through consultation with Jesse Bennett of Driftless Land Stewardship, LLC, the 2011 goat provider, past studies from Australia, and recommendations from the western U.S.A. A stocking rate of 86 goats per 0.5-hectare unit was used during the 2011 and 2012 field season. The 2012 goats belonged to Ben Robel of Vegetation Solutions, LLC. Based on goat body weights and metabolic class (nursing doe, kid, non-nursing doe) I calculated the animal unit equivalents (AUEs) of the goats to be 6.4 AUEs each year. I supplied the goats used in 2013, which were smaller framed than those used in 2011 and 2012, so using a head count would not apply the same browsing pressure on the site as in 2013. I calculated that 110 of these smaller goats would equal 6.4 AUEs in 2013, matching the browsing pressure of the previous two seasons. Goats were concurrently browsed on both sections of a treatment paddock (split plot), with 3.2 AUEs in each section, and then rotated to the next. A full rotation through all five replicate blocks took 30 days in 2011 and 2012—five two-day treatment sections plus five four-day treatment sections.

The goal was for goats to consume 90 percent of brush foliage in the heavily browsed paddocks during a rotation. One-day and two-day treatments were used during the first rotation of 2011 but were insufficient to reduce the majority of foliage. Browsing treatment length was doubled to two- and four-day treatments for the second 2011 rotation. In 2011, the first rotation began June 8 and ended June 22; the second rotation began July 18 and ended August 17. During 2012 the first rotation began June 7, 2012 and ended July 7, 2012. In both years, each paddock was rested a total of 38 days before beginning the second to allow browsed brush to regrow leaves.

The two- and four-day browse treatments were maintained for the first rotation of the 2012 field season. A drought began near the end of the first rotation resulting in a 17.8 cm (7”) precipitation deficit by the end of the summer (U.S. Drought Monitor, 2012, Figure 1 in Appendix A). The drought limited the regrowth of leaves and the four-day heavy browse treatment was shortened to three days due to lack of forage for the goats during the second rotation. The second rotation began July 16, 2012 and ended August 10, 2012.

Given the wet spring and subsequent summer drought in 2013, the delay of the Animal Care and Use Protocol approval, and the lack of regrowth following the initial browsing, only one rotation was conducted in 2013. The light browsing treatment was increased from two to three days, and the heavy browsing treatment was increased from four to five days in length in order to achieve the 50% and 90% defoliation benchmarks, respectively. The 2013 browsing started on July 1, 2013 and ended on August 11, 2013.

The initial interseeding in 2011 was followed by drought and no species from this planting were found in the 2012 or 2014 sampling. The split plot design placed half of the goats on the interseeded half of the treatment paddock, and the other half of the goats on the non-interseeded part of the treatment paddock. An electric net fence divided the herd.

Data Collection Methods

Vegetation Response to Browsing

Sampling occurred in spring of 2014, following protocols established in 2011. Permanent nested quadrats were used to monitor the effects of the treatments: 1-square-meter quadrats for herbaceous species; 5-square-meter circular quadrats for brush and sapling density and height. These permanent quadrats were selected based on a stratified random design to account for the influence of slope. Each half paddock was divided into a 3 by 3 grid totaling nine sections. A quadrat was then located at random within each of the nine sections. Precautionary buffers equal to the distance at which brush cover was measured (5 meters) were used when selecting quadrat location to ensure cover board readings would not overlap. The nail marking the quadrat was always positioned in the bottom left corner of the 1 x 1 meter quadrat when facing uphill (Figure 8).

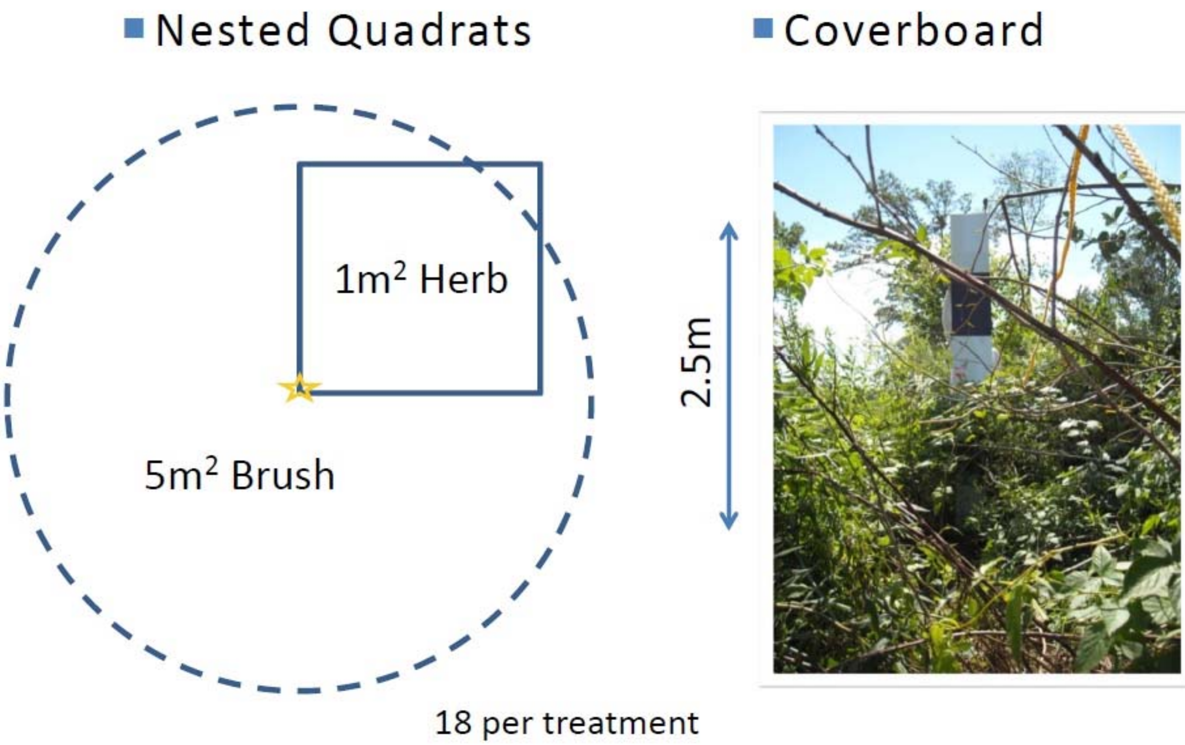


Figure 8. Nested quadrat layout and coverboard view through the brush at the site. Photo by Katie Baumann.

All quadrats were sampled for herbaceous species presence/absence and relative cover. Cover was visually estimated using six cover classes (0-5%; 5-25%; 25-50%; 50-75%; 75-95%; and 95-100%) in accordance with the Daubenmire method (Daubenmire, 1959). Six of the nine quadrat locations were randomly selected in 2011as the center of circular 5-square meter brush quadrats. All trees within each paddock were identified, measured for DBH and mapped with a GPS to obtain tree density prior to treatments in 2011.

Brush cover was estimated using a cover board at a distance of five meters taken both directions perpendicular to the hill slope (NARSC, 1999). The cover board is 2.5

meters tall by 0.25 meters wide and divided into five 0.5 meter bands of alternating black and white. It is a modification of another visual obstruction method, the Robel pole, which is used as an alternative to measuring vegetation biomass (NARSC, 1999, Figure 9). A coverboard is used to estimate percentage or density of vegetation cover rather than biomass. This method was chosen over others such as the line intercept method because of time constraints, acceptability in vegetation assessment and extremely thick brush. The coverboard also gives an additional dimension of brush density beyond stem count which was not expected to decline during the first years of the study.

Figure 9. Three treatments and coverboards. Cover board view in the three treatment types: Control, Lightly or Heavily Browsed.

The cover board was held upright by one person with the bottom of the coverboard centered at the nail marking the quadrat point. Another person stood five meters away, measured with five-meter rope perpendicular to the direction of the hill slope, and estimated the percentage of each of the five bands that were visually obstructed by vegetation using the same six Daubenmire classes used for herbaceous cover. Eye height for measurements was approximately one meter. Readings were taken both to the right and to the left of the quadrat point if facing uphill. Statistical analysis of both brush and herbaceous cover used the midpoint of each of the Daubenmire classes (2.5%, 15%, 27.5%, 62.5%, 85%, and 97.5%).

Brush stem counts were recorded by species. An individual stem was counted if there was no visible attachment to another stem at the surface. Stems that were not dead at the time of sample were counted as living. This was determined by scratching the bark on a twig; if the cambium layer was green underneath the bark, the brush or sapling was considered to be alive. Saplings are defined as any tree with a DBH of 9 cm or smaller.

Sampling occurred twice during the 2011 and 2012 growing seasons, once in late-May to early-June to capture spring ephemerals prior to goat introduction for that growing season and once after the second goat rotation in mid-August to capture summer and fall blooming species post-treatment. Brush were also sampled at both times in order to assess the immediate impacts of goat browsing treatment as well as treatment timing and brush recovery from early to late summer. Final sampling occurred once in 2014, throughout the month of June.

Abiotic Environmental Response to Browsing

Light availability was assessed through the measurement of photosynthetically active radiation (PAR) and leaf area index (LAI) using an AccuPAR LP-80 ceptometer (Decagon Devices 2010). Measurements were taken in late June of 2014 at six randomly selected quadrat points within each paddock (three in the unseeded and three in the seeded half). Although PAR is the direct measurement of light intensity, it varies with time of day, cloud conditions, and tilt and direction of the light wand. Therefore, LAI, an estimate of leaf surface area based on PAR readings both above and below the brush canopy, was used as a normalized indicator of light reaching the ground layer. To obtain LAI data, PAR readings were taken above the brush canopy (variable height) to measure PAR in full sunlight and at 0.5 meters (avoiding most herbaceous plants) to measure PAR at the average height that would be below brush canopy. The LAI is calculated using PAR that reaches the understory, also referred to as the variable tau (tau = below-canopy PAR - above-canopy PAR), (Decagon Devices, 2010).

The hand-held box of the light wand was held (level) above the nail marking the quadrat with the sensing wand pointed uphill. In some locations brush canopy was too high to reach for an accurate reading. This was remedied by taking a step or two to an area where a canopy-free reading could be achieved. The below-canopy reading was then taken at the original quadrat point. Quadrat points were measured regardless of brush cover. If there was no brushy vegetation at a quadrat, the above-canopy reading was taken at chest height and the below-canopy reading at the normal 0.5 meters. Light measurements were not taken in 2011. In 2012, sampling occurred before the first browsing rotation at the end of May and occurred in early June in 2014. Early spring and summer light levels were collected with this timing, prior to the goat browsing, and the spring following the third year of browsing to assess regrowth and changes in light penetration.

Litter depth was measured to the millimeter at three random points in all quadrats using a small ruler. This occurred during the second round of sampling in mid-August in 2011 and 2012, and in June of 2014. If a random point in the quadrat happened to be located directly on a rock, stump, etc. litter depth was recorded as zero.

Soil compaction measurements were obtained using a soil compaction tester, also known as a penetrometer, sampled at six random quadrats in each paddock. At each quadrat point three measurements were recorded and averaged. The penetrometer was pushed straight down into the ground at a steady rate until the meter reached the 300lb pressure threshold, at which the soil was too compact for root growth (DICKEY-john Corporation, 1987). The length of the rod submerged in the soil was then recorded to approximate the depth of soil available for optimal root growth. Due to the rocky and thin nature of the steep hillside soil, many sample depths were limited due to hitting rock, not the compaction of the soil. Estimation of the depth of root growth using this device is prone to fluctuations in accuracy depending on soil moisture content (DICKEY-john Corporation, 1987); however, when samples are taken in the same day under identical weather conditions, the results are useful to compare treatments and control without comparing between samples taken under different conditions.

Goat Dietary Selection

In the summer of 2011, 2012 and 2013, goat dietary intake was monitored for six days spaced over the full rotation. Six random goats (three in each half paddock) were each observed for five-minutes four times throughout the day, for forage species and type (herb, brush/tree foliage or twigs) consumed.

Goat Health Response to Browsing

In 2012 and 2013, goat health was assessed using FAMAHCA © test scores, body condition scores and body weights, collected 24 hours before the start of browsing and after the browsing within 24 hours of goat removal from paddocks. Body weight change, body condition score change and parasite load change were used to assess overall goat health as well as weight gain in kids raised for meat.

DATA ANALYSIS

Vegetation Response to Browsing Treatments

Brush/sapling cover, stem density, and herbaceous cover and species richness, were analyzed using a 2-way ANOVA PROC MIXED of SAS 9.4 (SAS Institute Inc., Cary, NC). The LSD test was used for multiple treatment comparisons using the LSMEANS statement of SAS 9.4 with letter grouping obtained using the SAS pdmix800 macro. Brush/sapling and herbaceous data were analyzed as a whole, as well as by species groups or individual species of interest. Data for groupings of species was analyzed for normalcy and rank transformed if needed for correction. In 2011 and 2012, rank transformed data included cover for graminoid, sun-favoring, partial sun-favoring, shade-favoring, erect and non-erect herbaceous species. Stem density data for individual species of *Rubus* were also transformed in this manner. Block was considered the experimental unit in each model. Class variables were block, treatment and quadrat. Models only contained a term for treatment, with block and quadrat considered random effects. Least squares means were considered different when protected by a significant F-test ($P \leq 0.05$).

Abiotic Environmental Response to Browsing

PAR was analyzed using a 2-way ANOVA using ANOVAs PROC MIXED of SAS 9.4 (SAS Institute Inc., Cary, NC) comparing the effects of goat browsing and split plot effect. The LSD test was used for multiple treatment comparisons using the LSMEANS statement of SAS 9.4 with letter grouping obtained using the SAS pdmix800 macro.

Litter depth and compaction, measured only in August in 2011, 2012 and June of 2014, were analyzed using a 2-way ANOVA using ANOVAs PROC MIXED of SAS 9.4 (SAS Institute Inc., Cary, NC) for individual years using a two-way ANOVA in SAS comparing effects of goat browsing and interseeding. The LSD test was used for multiple treatment comparisons using the LSMEANS statement of SAS 9.4 with letter grouping obtained using the SAS pdmix800 macro. Since litter depth was not measured in August of 2013, the spring 2014 litter depth measurements can only be compared descriptively to the 2011 and 2012 data.

Soil compaction readings with a penetrometer are very sensitive to moisture content (DICKEY-john Corporation, 1987) and the 2012 season was much drier than the 2011 or 2014 season. In addition, slightly different measurement reading methods for litter depth are suspected between years. Compaction levels were compared between treatments within years for trends.

The effects of treatments on abiotic factors were analyzed as a completely randomized block design using linear mixed models (PROC MIXED, SAS Inst. Inc., Cary, NC). Block was considered the experimental unit in each model. Class variables were block, treatment and quadrat. Models only contained a term for treatment, with block and quadrat considered random effects. Least squares means were considered different when protected by a significant F-test ($P \leq 0.05$).

Goat Dietary Selection

Goat dietary selection recordings were summed by type of forage consumed (brush, sapling, vine, bramble, forb, graminoid), and each type divided by the count of all recordings to assess the percent of each forage in the goat's diet, and goat behavior time budgets were recorded as percentages of time spent in various activities (eating, walking, chewing, laying, mineral, standing, drinking) for each year. Homogeneity was evaluated using a linear mixed model (PROC MIXED of SAS 9.4, SAS Institute Inc., Cary, NC). Goat was considered the experimental unit in each model. Class variables were year, block, treatment, and time. Models contained a term for year time and location, with block and treatment used as random terms. Models contained a term for place x year only because the interaction was significant at $P \leq 0.05$. The LSD test was used for multiple treatment comparisons using the LSMEANS statement of SAS 9.4 with letter grouping obtained using the SAS pdmix800 macro.

Kulcyznski's Similarity Index (KSI; Oosting, 1956) was applied to estimate selection discrimination exercised by the three goat herds (Ferreira et al., 2009). Kulcyznski's similarity index (KSI; $[(2c_i)/(a_i+b_i)] * 100$, where a_i=% basal cover of component i, b_i = % of component i detected in herbivore diets, and c_i=the lesser of a_i or b_i) was used to evaluate diet selection patterns for each goat herd in relation to botanical composition of pastures (Oosting, 1956). For the purposes of our analyses, we assumed that KSI values ≥ 80% indicated little or no discrimination (i.e., selection patterns were similar to plant availability), that KSI values between 21% and 79% indicated moderate discrimination, and that KSI values ≤ 20% indicated either strong preference for or avoidance of individual plant species. Preference and avoidance were distinguished from one another by comparing the proportion of goat diets composed of component i with basal cover of component i in paddocks.

Goat forage selections relative to their availability for the KSI were evaluated using linear mixed models (PROC MIXED, SAS Inst. Inc., Cary, NC). Goat was the experimental unit in each model. Class variables included year, block, treatment, time and location. Models included year, treatment location, year x treatment, year x location and treatment x location, with block treated as a random variable. Least squares means were considered different when protected by a significant F-test ($P \leq 0.05$).

Goat Health and Growth Response to Browsing

Before browsing and after browsing weight measurements for all goats were obtained to assess weight change, and analyzed using a paired t-test in SAS. Changes in weight as average daily gain (ADG), body condition scores (BCS) and FAMAHCA © were tested by class of goat (nursing does, kids, and non-nursing does) and were analyzed as completely randomized designs using mixed models (PROC MIXED, SAS Inst. Inc., Cary, NC). Goat was considered the experimental unit, individually identifiable by ear tags. For goat ADG data, class variables were breed, class and year. For goat BCS and FAMAHCA © data, class variables were class and year. Models contained terms for breed, class, year and 2 way interactions. The LSD test was used for multiple treatment comparisons using the LSMEANS statement of SAS 9.4 with letter grouping obtained using the SAS pdmix800 macro. For all statistical tests, significance was declared at a *P*-value of $\leq$0.05, and a statistical trend was noted at a *P*-value of $\leq$0.10. Post hoc analyses for treatment differences were conducted if interactions were significant.

To place the YLWA goat kid growth data in context with data collected by independent research institutes in Maryland and Oklahoma during those same years, the effects of data set origin and year were assessed for average daily gain in goat kids as a linear mixed model (PROC MIXED, SAS Inst. Inc., Cary, NC). Goat was the experimental unit in each model. Class variables included place, year, and place x year. Models contained a term for place x year only because the interaction was significant at $P \leq 0.05$.

CHAPTER 2: Plant Species Cover and Richness Changes Following 3 Years of Brush Management with Meat Goats in an Oak Savanna in the Driftless Area of Wisconsin

Cherrie A. Nolden[1], John A. Harrington[1, 2], Katherine Baumann[3], Julia M. Ela[4]. [1]University of Wisconsin-Madison Department of Agroecology, canolden@wisc.edu, jaharrin@wisc.edu; [2]University of Wisconsin-Madison Department of Landscape Architecture; [3]Nature's Capital, LLC, Boise, ID, katie.baumann28@gmail.com; [4]National Fish and Wildlife Foundation, Washington D.C., ela.juliam@gmail.com

Contact: Cherrie A. Nolden; 1156 Animal Sciences Department, 1675 Observatory Drive, University of Wisconsin-Madison, Madison, WI 53706; 608-477-1981; canolden@wisc.edu

ABSTRACT

Goats managed specifically to reduce brush is demonstrated effective in other regions of the world, but there is little knowledge of the botanical and abiotic impacts of this ruminant vegetation management tool. We tested three levels of goat browsing (Control, Heavily and Lightly browsed) applied over 3 years in a randomized complete block design with 5 blocks at the Yellowstone Lake Wildlife Area in Wisconsin from 2011 to 2014. There was a significant reduction in % brush cover between the control and heavily browsed treatments by the spring following 3 years of goat browsing. There were no significant differences in brush height until the spring following 3 years of browsing with goats, when the brush within the Heavily browsed treatments was significantly shorter than brush in the Control treatments. There were significantly more top-killed woody stems in 2014 in the Heavily browsed treatment for both clonal species and total woody stems. Heavily browsed

treatments showed significantly greater density of dead woody stems in 2014 than Lightly browsed or Control treatments. Overall herbaceous species and forb species richness decreased in Control treatments relative to Heavily browsed treatments in 2014. Herbaceous cover was greater in the Heavily browsed treatments than then Control treatments in 2014, largely due to non-native aggressive forb species. Individual species in the aggressive category for all forms of herbaceous plants at the research treatment showed no significant increases in cover between treatments. By 2014, Heavily browsed treatments had a trend for a greater cover of upright forb species than Control treatments. No significant difference in litter depths or soil compaction between treatments were detected during this study. Sunlight penetration, measured as photosynthetically active radiation (PAR) detectable below the brush layer, was not significantly different between treatments in 2012 or 2014. These results suggest that after 3 years of high levels of goat browsing positive impacts are occurring and negative impacts are minimal or nonexistent.

INTRODUCTION

Oak savanna communities in the Upper Midwest have been declining due to woody encroachment (Nuzzo, 1986; Henderson & Epstein, 1995; Solecki, 1997; Nowacki and Abrams, 2008). They were estimated to cover 3 million ha prior to the arrival of Europeans, but less than one half of 1% of this community remains today (Curtis, 1959; Compton et al., 2003). Upper Midwestern oak savanna ecosystems are characterized by widely spaced oak trees with an understory of herbaceous forb, prairie grass and sedge species (Curtis, 1959; Taft 1997). The removal of fire and grazing management in these systems, coupled with agriculture/urban development, has resulted in woody plant encroachment (Compton et al., 2003).

Interest in low-labor, low-cost, low-liability, low-externalities, high-effectiveness, high flexibility, high-specificity and repeatable-within-season methods for reducing woody plant encroachment has led to the evaluation of rotational goat browsing as a management tool (Hart, 2006; Papanastasis, 2009; Harrington and Kathol, 2009; Hart, 2012). Hand removal of brush is labor intensive, application of herbicides on the stumps is not always desirable or completely effective, and fire is not always successful at reducing woody species due to the lack of fuel in the understory and weather conditions (Henderson, 1995; Haney and Apfelbaum, 1995; Anderson and Bowles, 1999; Will-Wolf and Stearns, 1999; Compton et al, 2003; McCarron and Knapp, 2003; Heisler et al., 2004; Sheuyange et al., 2005; Nowacki and Abrams, 2008; Harrington and Kathol, 2009; Staffen, 2010; Marcora et al., 2018; Daryanto, et al., 2019). Goats are natural browsers that can consume a diet of primarily woody vegetation while maintaining good animal performance (Griffin et al., 2005; Hart, 2006; Hart, 2012; Schafer, 2013; Elias and Tischew, 2016). Managed goat browsing over multiple years with low and high browsing intensity hasn't been studied for its impacts on oak savanna communities in the Upper Midwest (Rathfon et al., 2014), but managed grazing as a tool to restore ecosystem structure through clearing of the overgrown woody understory has been suggested for decades (Johnston and Peake 1960; Green, 1980; Sharrow et al. 1989; Hart, 2006; Papanastasis, 2009; Harrington and Kathol, 2009; Hedtke et al. 2009; Papanastasis, 2009; Kleppel and LaBarge 2011; Teague et al., 2011; Garcia et al., 2012; Hart, 2012; Daryanto et al., 2019). Hence, managed goat browsing may be a potential conservation management tool that could open the woody understory enough to reintroduce fire (Papachristou et al., 2005; USDA-FS, 2012; Rathfon et al., 2014; Elias and Tischew, 2016).

The objectives of this study were to apply rotational goat browsing at 2 intensity levels for 3 years in a degraded oak savanna and measure changes in 1) brush height, cover and species richness, 2) herbaceous species richness and cover, 3) light penetration, 4) litter depth, and 5) soil compaction. Our hypothesis is that goats managed for brush biomass removal could reduce brush height, cover and species richness, increase herbaceous species richness and cover, and increase light penetration, without litter loss or soil compaction. This information would help landowners and managers evaluate the potential of goats as a conservation tool in degraded oak savannas.

METHODS

Treatment Characterization

To compare the impact of 2 levels of browsing with no goat browsing on overgrown oak savanna, the study was established at the Yellowstone Lake Wildlife Area (YLWA) in Lafayette County (43^{o}02’N, 89^{o}90’W), owned and managed by the Wisconsin Department of Natural Resources. The site, with a ridge valley topography, contains degraded oak woodland, dominated by bur and white oak (*Quercus macrocarpa* Michx. and *Quercus alba* L., respectively) with well drained shallow silt loam soils, and rough unglaciated steep terrain that allowed it to “escape the plow.” It was severely overgrazed in 1989 when the

WDNR purchased the property, and a forestry thinning and mowing was conducted in 2008 to reduce the oak woodland to 30% oak canopy.

The vegetation type is typical of dry calcareous savanna, as is described by Will-Wolf and Stearns (1999). The site has remnant prairie patches with native forbs and grasses such as culver's root (*Veronicastrum virginica*), golden alexanders (*Zizia aurea*), New Jersey tea (*Ceanothus americanus*), skyblue aster (*Symphyotrichum oolentangiense*), New England aster (*Symphyotrichum novae-angliae*), paleleaf woodland sunflower (*Helianthus strumosus*), shooting star (*Dodecatheon meadia*), yellow-pimpernel (*Taenidia integerrima*), naked-flowered tick trefoil (*Desmodium nudiflorum*), and American hogpeanut (*Amphicarpaea bracteata*), little bluestem (*Schizachyrium scoparium*), Indiangrass (*Sorghastrum nutans*) and prairie dropseed (*Sporobolus heterolepis*). The site has been invaded by woody species and Eurasian temperate grasses in the open areas. In southwest Wisconsin, the recent mean annual precipitation is 561 mm, with a precipitation peak in May and dry conditions in June. This region has a mean temperature of 18.25 C in the growing months of April to August and a mean temperature of −3.2 C in the winter months of November through February (Monroe Municipal, 2019).

Experimental Design

In 2011, a randomized complete block design with 5 replicates was located within the 12-hectare site. Each 1.5-hectare block was divided into three 100-meter by 50-meter paddocks (0.5 hectares). Paddocks were positioned mid-slope in such a way that the steepest part of the slope occurred in the center of every paddock. Each paddock was randomly assigned a goat browsing treatment: lightly browsed (LB) or heavily browsed (HB) or a no browsing control (C) and fenced with portable electrified netting. Paddocks were divided in half across treatments with a split plot treatment of interseeding. One half of each paddock was randomly assigned and broadcasted with a native seed mix while the other half received no treatment. As interseeding was anticipated to affect goat browse preference at some time in the future, 3.2 animal unit equivalents (AUEs) of goats were fenced within each half paddock. All block units were buffered with a 1.5-meter mowed swath.

Livestock Rotation Schedule

Objectives for the LB paddocks was a 50% defoliation of all of the woody vegetation within reach of the goats, and 90% defoliation for the HB treatments, with equal number of days of browsing applied to each replicate within the rotation. These targets allowed for browsing periods to be adapted to weather and forage availability. The assessment of 50% and 90% defoliation was a qualitative one made collectively by the goat browsing contractors and the researchers each year as the season progressed. The first full rotation of the goats through all of the treatment paddocks took 15 days in 2011, from June 8 to June 22, and did not achieve the desired 90% defoliation in the HB treatments with 2 days of browsing, nor the 50% defoliation in the LB treatments with 1 day of browsing. After a 38 day rest to allow brush to regrow leaves, the second rotation of browsing treatments in 2011 consisted of 2 days of browsing for the LB plots and 4 days of browsing in the HB plots. In 2012, the 5 LB plots were browsed for 2 days, and the 5 HB plots were browsed for 4 days, from June 7 to July 7, for the first rotation. The second 2012 rotation was impacted by a drought, so the HB plots were browsed for 3 days and the LB for 2 days twice, with a 38-day rest between browsings. Given the wet spring in 2013, goat browsing ran from July 1 to August 11, and the LB treatment was increased to 3 days and the HB treatment was increased to 5 days to achieve the 50% and 90% defoliation benchmarks, respectively. A second browsing in 2013 was precluded by a lack of regrowth within the season.

Vegetation Measurements

Vegetation sampling occurred in June of 2011, 2012, and 2014. Permanent nested quadrats were used to monitor the effects of the treatments: 1-square-meter quadrats for herbaceous species; 5-square-meter circular quadrats for brush and sapling density and height. These permanent quadrats were selected based on a stratified random design to account for the influence of slope. Each half paddock was divided into a 3 by 3 grid totaling nine sections. A quadrat was then located at random within each of the nine sections. Precautionary buffers equal to the distance at which brush cover was measured (5 meters) were used when selecting quadrat location to ensure adjacent quadrat readings would not overlap. The nail marking the quadrat was always positioned in the bottom left corner of the one by one-meter quadrat when facing uphill.

All quadrats were sampled for herbaceous species presence/absence and relative cover. Cover was visually estimated using six cover classes (0-5%; 5-25%; 25-50%; 50-75%; 75-95%; and 95-100%) in accordance with the Daubenmire method (Daubenmire, 1959). Any woody species within a quadrat were also assigned cover classes for quadrat-level brush cover estimates. Six of the nine quadrat locations were randomly selected in

2011as the center of circular 5-square meter brush quadrats. All trees within each paddock were identified, measured for DBH and mapped with a GPS to obtain tree density prior to treatments in 2011.

Brush cover was estimated using a cover board at a distance of five meters taken both directions perpendicular to the hill slope (NARSC, 1999). The cover board is 2.5 meters tall by 0.25 meters wide and divided into five 0.5 meter bands of alternating black and white. It is a modification of another visual obstruction method, the Robel pole, which is used as an alternative to measuring vegetation biomass (NARSC, 1999). A coverboard is used to estimate percentage or density of vegetation cover rather than biomass. This method was chosen over others such as the line intercept method because of time constraints, acceptability in vegetation assessment and extremely thick brush. The coverboard also gives an additional dimension of brush density beyond stem count which was not expected to decline during the first years of the study.

The cover board was held upright by one person with the bottom of the coverboard centered at the nail marking the quadrat point. Another person stood five meters away, measured with five-meter rope perpendicular to the direction of the hill slope, and estimated the percentage of each of the five bands that were visually obstructed by vegetation using the same six Daubenmire classes used for herbaceous cover. Eye height for measurements was approximately one meter. Readings were taken both to the right and to the left of the quadrat point if facing uphill. Statistical analysis of both brush and herbaceous cover used the midpoint of each of the Daubenmire classes (2.5%, 15%, 27.5%, 62.5%, 85%, and 97.5%).

Brush stem counts were recorded by species. An individual stem was counted if there was no visible attachment to another stem at the surface. Stems that were not dead at the time of sample were counted as living. This was determined by scratching the bark on a twig; if the cambium layer was green underneath the bark, the brush or sapling was considered to be alive. Saplings are defined as any tree with a DBH of 9 cm or smaller.

Abiotic Measurements

Light availability was assessed through the measurement of photosynthetically active radiation (PAR) and leaf area index (LAI) using an AccuPAR LP-80 ceptometer (Decagon Devices 2010). Measurements were taken in spring of 2014 at six randomly selected quadrat points within each paddock (three in the unseeded and three in the seeded half). Although PAR is the direct measurement of light intensity, it varies with time of day, cloud conditions, and tilt and direction of the light wand. Therefore, LAI, an estimate of leaf surface area based on PAR readings both above and below the brush canopy, was used as a normalized indicator of light reaching the ground layer. To obtain LAI data, PAR readings will be taken above the brush canopy (variable height) to measure PAR in full sunlight and at 0.5 meters (avoiding most herbaceous plants) to measure PAR at the average height that would be below brush canopy. The LAI was calculated from PAR that reached the understory, also referred to as the variable tau (tau = below-canopy PAR - above-canopy PAR) (Decagon Devices, 2010).

The hand-held box of the light wand was held level above the nail marking the quadrat with the sensing wand pointed uphill. In some locations brush canopy was too high to reach for an accurate reading. This was remedied by taking a step or two to an area where a canopy-free reading could be achieved. The below-canopy reading was then taken at the original quadrat point. Quadrat points were measured regardless of brush cover. If there was no woody vegetation at a quadrat, the above-canopy reading was taken at chest height and the below-canopy reading at the normal 0.5 meters. Light measurements were not taken in 2011. In 2012, sampling occurred before the first browsing rotation at the end of May and again after the second rotation at the end of August. In 2014, sampling occurred in early June.

Litter depth was measured to the centimeter at three random points in all quadrats using a small ruler and then averaged. This occurred during the second round of sampling in mid-August in 2011 and 2012, and in June of 2014. If a random point in the quadrat happened to be located directly on a rock, stump, etc. litter depth was recorded as zero.

Soil compaction measurements were obtained using a soil compaction tester, also known as a penetrometer, sampled at six random quadrats in each paddock. At each quadrat point three measurements were recorded and averaged. The penetrometer was pushed straight down into the ground at a steady rate until the meter reached the 300lb pressure threshold, at which the soil was too compact for root growth (DICKEY-john Corporation, 1987). The length of the rod submerged in the soil was then recorded to approximate the depth of soil available for optimal root growth. Due to the rocky and thin nature of the steep hillside soil, many sample depths were limited due to hitting rock, not the compaction of the soil. Estimation of the depth of root growth using this device is prone to fluctuations in accuracy depending on soil moisture content (DICKEY-john Corporation, 1987); however, when samples are taken in the same day under identical weather conditions, the results are useful to compare treatments and control without comparing between samples taken under different conditions.

DATA ANALYSIS

Brush/sapling cover and stem density, and herbaceous cover and species richness, were analyzed using a PROC MIXED analysis of variance (ANOVA) in SAS comparing the effects of goat browsing and treatment effect. All species data were analyzed as a whole, as well as by species groups or individual species of interest. Table 12 in Appendix A shows which plant species were assigned to the analyzed species groups. Data for groupings of species were analyzed for normalcy and transformed by ranking if needed for correction. Significance was assessed at $P \leq 0.05$.

PAR was analyzed using a PROC MIXED analysis of variance (ANOVA) in SAS comparing the effects of goat browsing and split plot effect.

Litter depth and compaction, measured only in August in 2011, 2012 and June of 2014, were analyzed for individual years using a PROC MIXED ANOVA in SAS comparing effects of goat browsing. Since litter depth was not measured in August of 2013, the spring 2014 litter depth measurements can only be compared descriptively to the 2011 and 2012 data.

Soil compaction readings with a penetrometer are very sensitive to moisture content (DICKEY-john Corporation, 1987) and the 2012 season was much drier than the 2011 or

2014 season. Compaction levels were compared between treatments within years for trends. A Student's t-test in SAS with *P*-values at $P \leq 0.05$ was considered significant.

Block was considered the experimental unit in each model. For woody stem counts, woody species cover by species and year, herbaceous species cover and count by year and species, aggressive species cover and count in 2014, species group cover and counts by year, cover board bands by year, shrub height, shrub cover, litter depth, soil compaction, and leaf area index, class variables were block, treatment and quadrat. Models only contained a term for treatment, with block and quadrat considered random effects. Least squares means were considered different when protected by a significant F-test ($P \leq 0.05$).

RESULTS

Woody Species Results

Brush Cover

Brush cover, when measured at each quadrat, was significantly reduced after 3 years of goat browsing. There was no significant difference in brush cover between treatments at the start of the project in spring of 2011 ($P = 0.7417$, SE = 5.6498). By 2014, Control treatments had significantly more brush cover than Heavily browsed treatments ($P = 0.0265$, SE = 6.4). Goat browsing in the Heavily browsed treatments reduced brush cover by 17.36% in 2014.

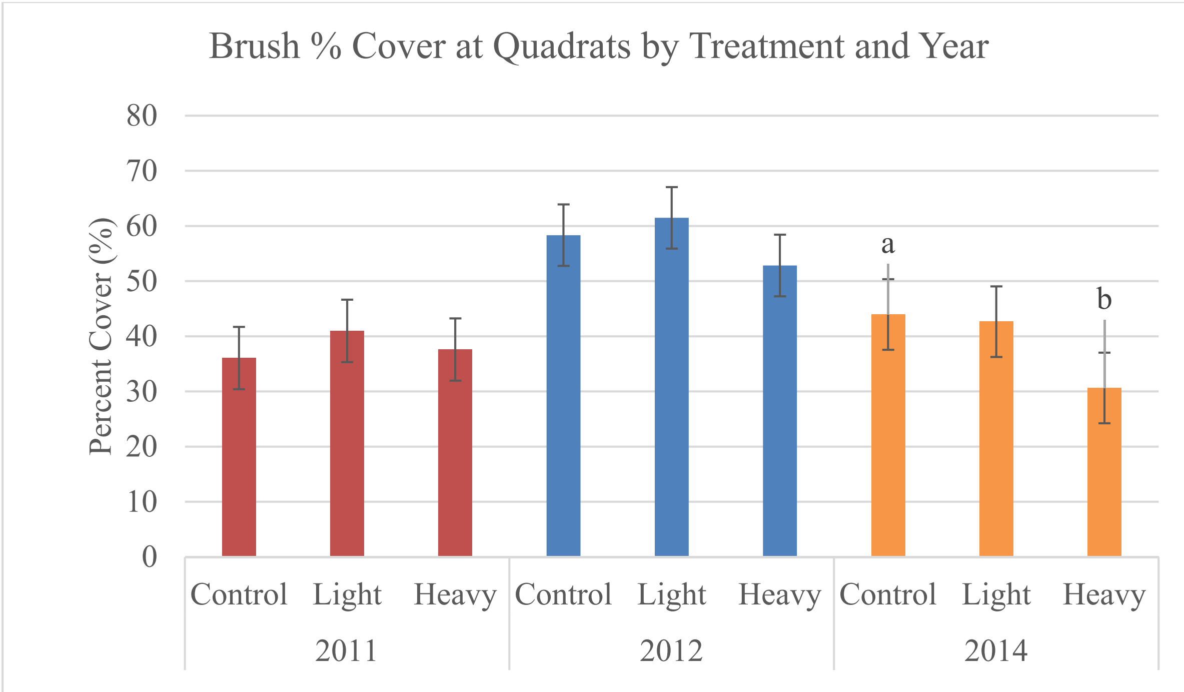


Figure 1. Graph of brush cover by treatment and year. Bars represent the standard error of the means. Letters indicate significance between treatments within year ($P < 0.05$) and no letter indicates no difference. There was a significant reduction in % brush cover between the control and heavily browsed treatments by the spring following 3 years of goat browsing.

Brush cover, as measured with a coverboard at each of 5 bands above the ground, showed similar results to the quadrat cover measurements. Brush cover was reduced significantly in the Heavily browsed treatments, relative to the Control treatments, following 3 summers of goat browsing.

There was no significant difference between bands or treatments at the start of the study in 2011. In the spring of 2012, all bands showed greater leaf cover than in 2011, but the only band showing significant differences between treatments in 2012 was the band closest to the ground. In this Band 1 in 2012, there was signifcantly less leaf cover in the Heavily browsed treatments than in the Control treatments ($P = 0.0293$, SE = 3.4244). The

Control treatments had 3.75% more brush cover, which was a 4.3% increase over the Heavily browsed treatments.

Greater changes in brush cover were documented in the spring following the third year of goat browsing. The upper bands of the 2014 coverboard data showed significant decreases in brush cover in the Heavily browsed treatments relative to the Control treatments. At Band 3, Control treatments had significantly higher brush cover than Heavily browsed treatments ($P = 0.0474$, SE = 8.57). There was 19.5% more brush cover at this level in the Control treatments than in the Heavily browsed treatments. At Band 4, Control treatments showed a trend for more brush cover than the Heavily browsed treatments in 2014 ($P = 0.0647$, SE = 8.75). Brush cover at Band 4 was 28% greater in Control treatments versus Heavily browsed treatments, which was a 53% difference between treatments. At Band 5, which was between 2 and 2.5 meters above the ground, Control treatments had significantly more brush cover than Heavily browsed treatments in 2014 ($P = 0.0369$, SE = 8.1). Brush cover was 32% greater in Control treatments versus Heavily browsed treatments at Band 5, which was a 65% difference between treatments.

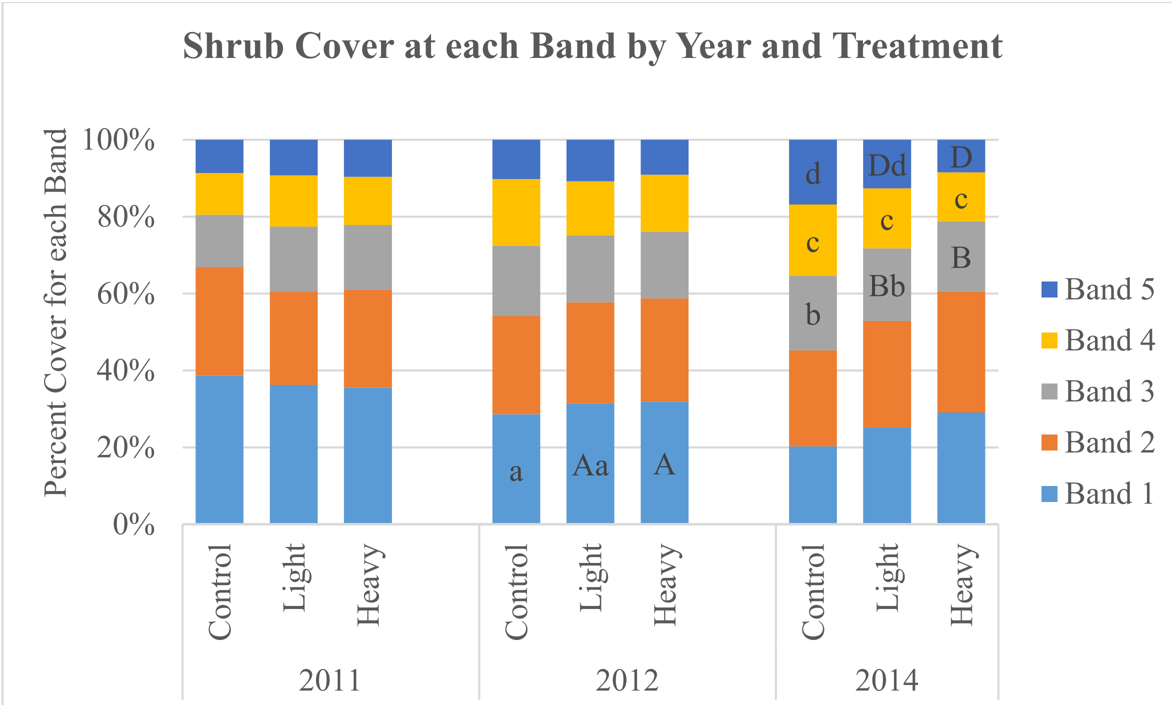


Figure 2. Brush cover at each band by year and treatment. Letters differing by capitalization indicate significant differences ($P < 0.05$) between bands within year. Letters with equivalent capitalization indicate a trend ($P < 0.1$) within year. The band closest to the ground showed a trend for a difference in % brush cover with Heavily browsed treatments showing less brush cover than Control treatments. By the spring following 3 years of goat browsing, there was a trend for a reduction in brush cover at both the topmost band and the second from the top in the Heavily browsed treatments relative to the Control treatments.

<u>Brush Height</u>

There was no significant difference in brush height between treatments at the start of the research in spring of 2011 ($P = 0.6682$, SE = 0.0887). By 2014, Control treatments had significantly taller brushs than Heavily browsed treatments ($P = 0.0184$, SE = 0.11). Goat browsing in the Heavy treatments resulted in a 25% decrease in brush height in 2014, which was a 0.44 meter difference between Heavy and Control treatments. Between 2011 and 2014, all treatments experienced brush height increases, with Control treatments growing

49% taller, Lightly browsed treatments 44% taller, and Heavily browsed treatments 26% taller.

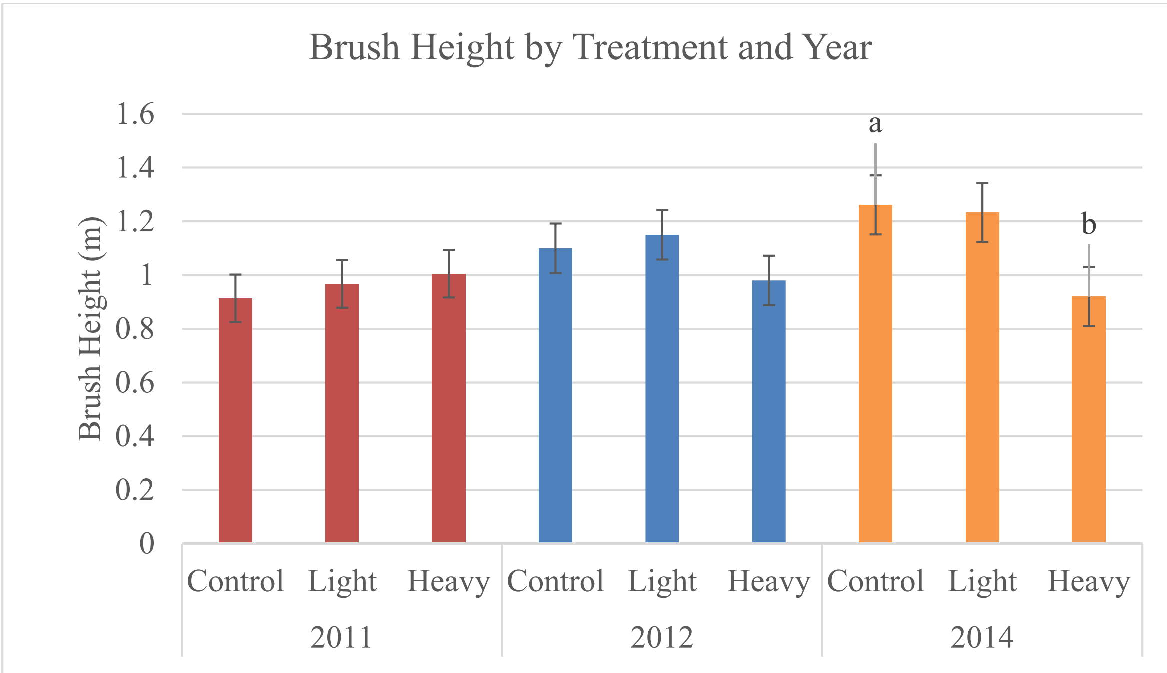


Figure 3. Brush height by treatment and year. There were no significant differences in brush height until the spring following 3 years of brush browsing with goats, where the Heavily browsed treatments showed significantly shorter brush than the Control treatments. Letters indicate significance between treatments within year ($P < 0.05$).

Dead Woody Stem Density in 2014

In order to assess if the goats were able to reduce the woody stem count, living and dead woody stem counts were evaluated. The count of dead stems doesn't imply that the plant is dead, but only that the particular stem is no longer alive and sending carbohydrates to maintain the root stores.

Clonal brush species were anticipated to be less impacted by goat browsing than non-clonal species. By 2014, Heavily browsed treatments had significantly more top-killed clonal brush species stems per 5 square meters than Lightly browsed or Control treatments (*P* = 0.0264, SE = 1.7825). No difference in clonal species was detected prior to the 2014 floral inventory. There were 5.8 more dead clonal stems in Heavily browsed treatments than in the control treatments in 2014, which was a 43% increase in dead clonal species stem density. Heavily browed treatments in 2014 had significantly more dead woody stems than Light or Control treatments (*P* = 0.0185, SE = 1.8174). There were 7.92 more dead stems in the Heavily browsed treatments than the Control treatments, which was a 48.2% increase in dead stems from goat browsing.

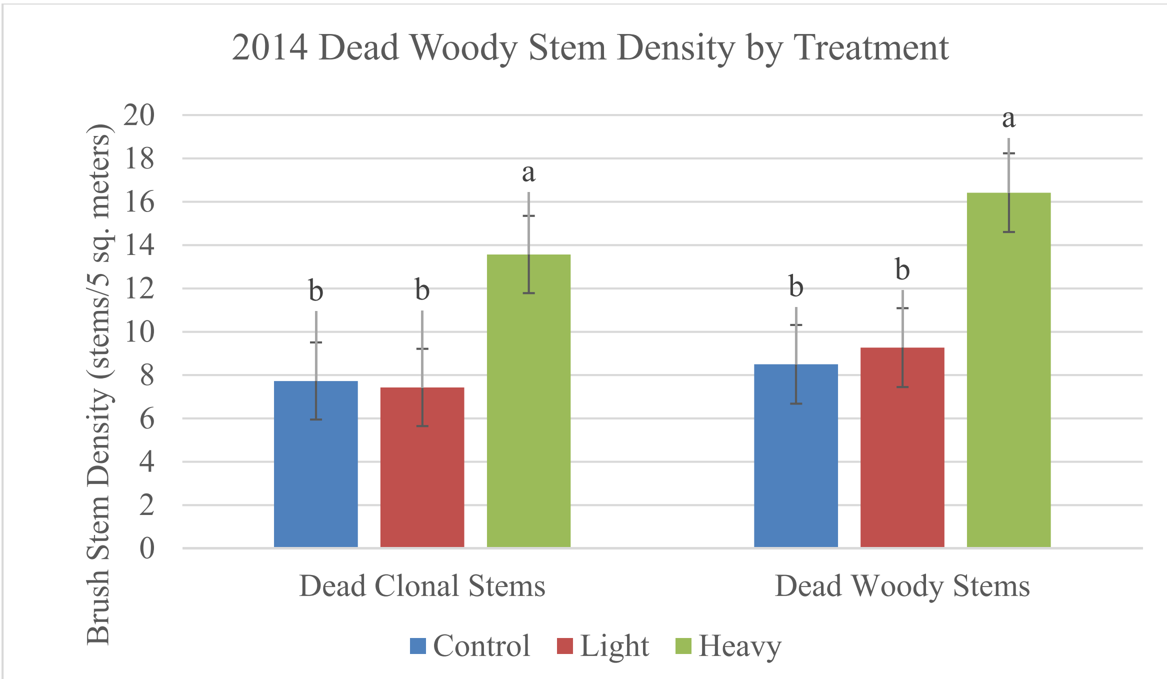


Figure 4. 2014 dead woody stem density by treatment. There were significantly more dead woody stems in 2014 in the Heavily browsed treatment for both clonal species and total woody stems. Letters indicate significance between treatments within year ($P < 0.05$).

Top-killed Woody Brush in 2014

Heavily browsed treatments had more dead aggressive woody brush than Lightly browsed treatments in 2014 ($P = 0.0492$, SE = 0.1836). There were 0.73 more dead brush in the Heavily browsed treatments, which was a 92% increase over the number in the Lightly browsed treatments.

Heavily browsed treatments had significantly more top-killed non-clonal woody brush than Control treatments in 2014 ($P = 0.0118$, SE = 0.6912). There were 2.8 more dead brush stems, a 97% increase over the number of dead brush of non-clonal species in the Control treatments in 2014.

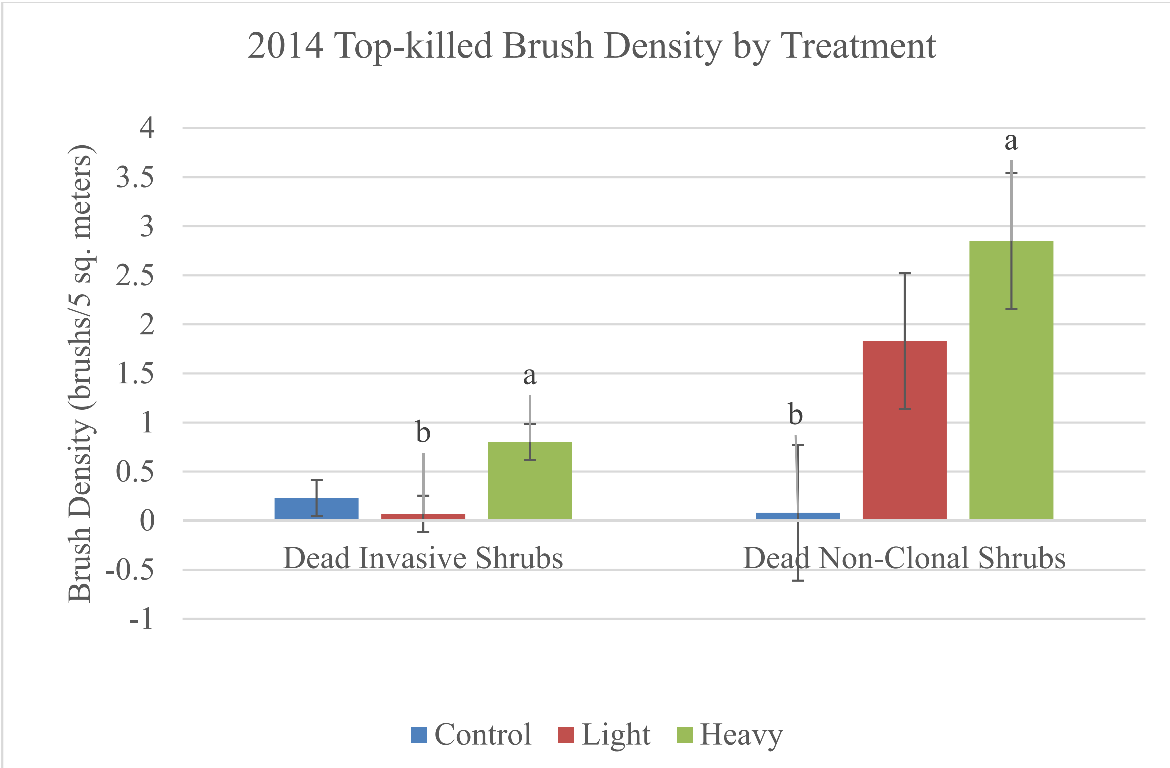


Figure 5. 2014 top-killed brush density by treatment. Heavily browsed treatments showed significantly greater density of dead woody stems in 2014 than Lightly browsed treatments for aggressive species, and Control treatments for non-clonal brush. Letters indicate significance between treatments within year ($P < 0.05$). Dead refers to stems, not plants.

Herbaceous Species Results

<u>Herbaceous Species Richness</u>

Goat browsing over 3 years resulted in an increase in non-woody herbaceous species richness in both the Heavily and Lightly browsed treatments relative to the Control treatments, with the primary richness being gained as forb species in the Heavily browsed treatments. There was no difference in herbaceous species richness between the study plots pre-treatment in 2011 ($P = 0.6765$, SE = 0.4168). By 2014, Control treatments had significantly lower herbaceous species richness than Heavily or Lightly browsed treatments

(P = 0.0096, SE = 0.6719) There were 1.67 more herbaceous species recorded in Heavily browsed treatments than in control treatments, which was a 16% increase in herbaceous species richness over the Control treatments.

There was no significant difference in graminoid species richness between treatments in 2011 (P = 0.1588, SE = 0.1018), and goat browsing treatments induced no significant difference in 2014 (P = 0.4184, SE = 0.1994).

There was no significant difference in forb richness between plots prior to treatments in spring of 2011 (P = 0.5044, SE = 0.3813). On average, there were 2.25 forb species per quadrat in 2011. By 2014, Heavily browsed treatments had a greater forb species richness than Control treatments (P = 0.0179, SE = 0.5353). There were 1.7 more forb species or a 19% forb increase in Heavily browsed treatments compared to the Control treatments. Lightly browsed treatments were not significantly different than either Control or Heavily browsed treatments for forb species richness in 2014.

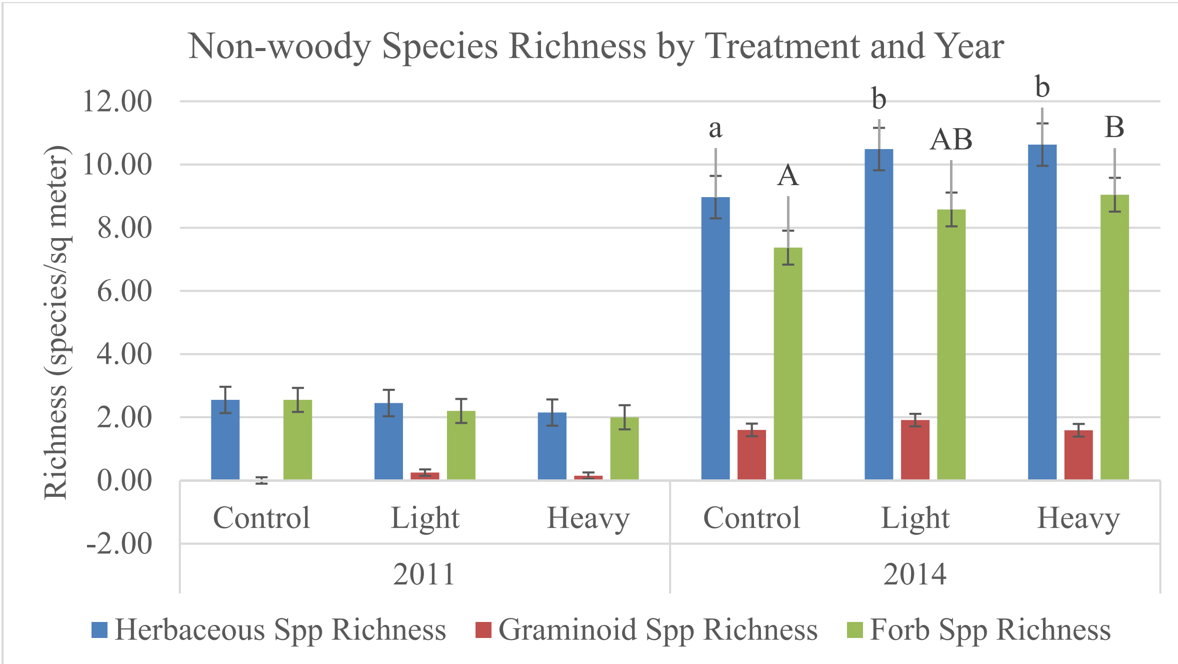


Figure 6. Non-woody species richness by treatment and year. Different letters indicate significance between treatments for a given species group, within year ($P < 0.05$). Overall herbaceous species richness decreased in Control treatments relative to Lightly or Heavily browsed treatments in 2014. There was a significant decrease in forb species richness in Control treatments relative to Heavily browsed treatments in 2014.

The majority of the forb species richness increase in 2014 was due to aggressive species. There was no significant difference in aggressive forb richness between treatments at the start of the project in spring of 2011 ($P = 0.6243$, SE = 0.2072), but by 2014, Heavily browsed treatments had a significantly higher aggressive forb species richness than Control treatments ($P = 0.0247$, SE = 0.2060). There were 0.8 more aggressive forb species per square meter in Heavily browsed treatments than in Control treatments in 2014, which was a 38% increase in aggressive forb species richness. Although there was a significant increase in aggressive forb richness Heavily browsed treatments, individual species in the aggressive category for all types of plants at the research treatment showed no significant increases in richness between treatments in 2014. There was a trend (*P* < 1.0) for a greater aggressive forb richness in Heavily browsed treatments vs. Control treatments for the following species: Burdock (*Arctium minus*) (*P* = 0.0557), Common Mullein (*Verbascum thapsus*) (*P* = 0.0542), and Bull Thistle (*Cirsium vulgare*) (*P* = 0.0604).

Herbaceous Species Cover

We expected an increase in herbaceous cover with a reduction in brush over time. At the start of the research in 2011, there was no difference in herbaceous species cover between treatments (*P* = 0.8675, SE = 3.0024). By 2014, Heavily browsed treatments had a significantly greater herbaceous species cover than Control treatments *(P* = 0.0436, SE = 12.7537). Heavily browsed treatments had 21.5% more herbaceous cover.

The majority of the increase in herbaceous species cover was due to a noticeable increase in forb cover, with Heavily browsed treatments having 93% forb cover and Control treatments having 76% forb cover, however this increase was not significant. treatments.

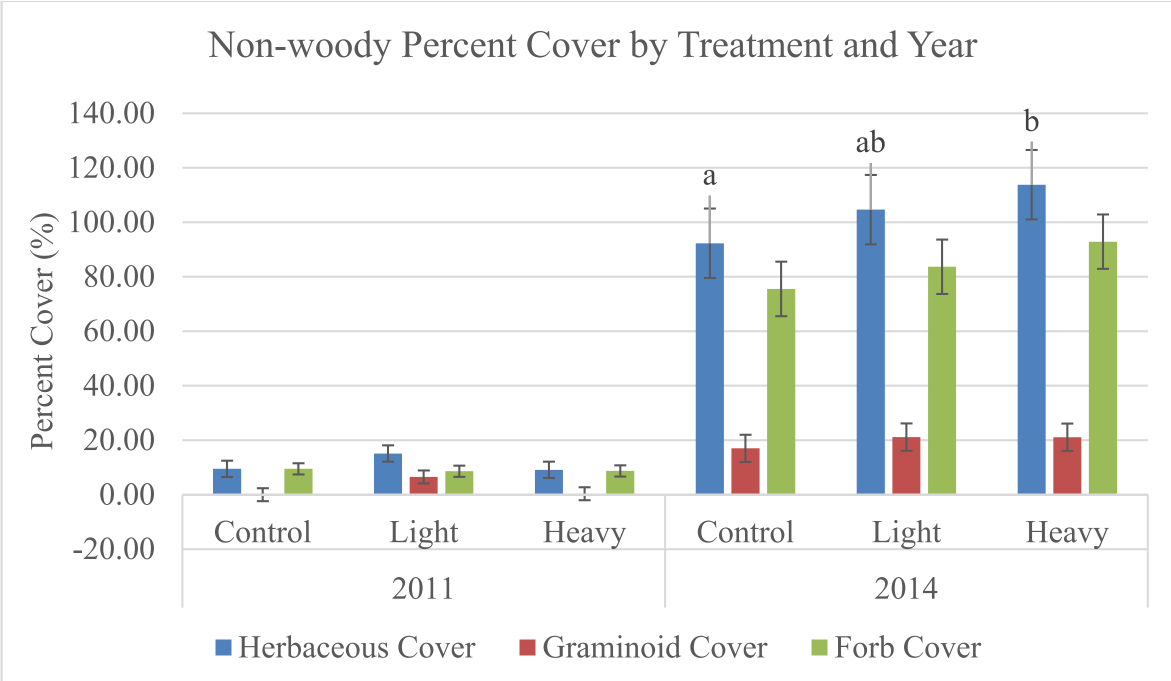


Figure 7. Non-woody percent cover by treatment and year. Letters indicate significance between treatments within year ($P < 0.05$). Overall herbaceous cover was greater in the Heavily browsed treatments than then Control treatments in 2014.

Forb cover increased differentially among forb species present in treatments in 2014. Percent cover of aggressive forbs and upright forbs increased more than other types. There was no significant difference in aggressive forb cover between treatments at the start of the project in spring of 2011 ($P = 0.7531$, SE = 1.6638), where average cover was around 3.5% in 2011. By spring of 2014, Heavily browsed treatments had a significantly higher aggressive forb species cover than Control treatments ($P = 0.0313$, SE = 4.3319). Aggressive forb species cover in Heavily browsed treatments was 13.3% greater than in Control treatments in 2014, which was a 49% increase in aggressive forb species cover between treatments.

Although there was a significant increase in aggressive forb cover in Heavily browsed treatments, individual species in the aggressive category for all types of plants at the research treatment showed no significant increases in cover between treatments in 2014. There was a trend ($P < 1.0$) for a greater aggressive forb cover in Heavily browsed treatments vs. Control treatments for the following species: Burdock ($P = 0.070$), Common Mullein ($P = 0.055$), and Bull Thistle ($P = 0.060$).

By 2014, Heavily browsed treatments had a trend for a greater cover of forb species with erect growth forms than Control treatments ($P = 0.0847$, SE = 7.7516). Table 12 in Appendix A shows the species that comprise the erect and other forms. There was an 11.7% greater erect forb cover in the Heavily browsed treatments in 2014,

Abiotic Results

There was no significant difference in litter depth between treatments in 2011 ($P = 0.5652$, SE = 0.6411), nor in 2014 ($P = 0.7451$, SE = .6411). Heavily browsed treatments had a trend for a shallower litter depth in 2012 than Control or Lightly browsed treatments ($P = 0.0559$, SE = 5.0798). Litter depth in the Heavily browsed treatments was 12.1 cm less than the Control treatments in 2012, which was a 35% reduction in overall litter depth in 2012. The treatment differences in 2014 were unremarkable.

Sunlight penetration, measured as photosynthetically active radiation detectable below the brush layer, was not significantly different between treatments in 2012 ($P = 0.2256$, SE = 2.5535), or in 2014 ($P = 0.1141$, SE = 0.52). It was not measured in 2011.

There was no significant difference in soil compaction between treatments in 2014 (P = 0.7644, SE = 1.3).

DISCUSSION

Significant reductions in living woody stems, brush cover and brush height in the Heavily browsed treatments occurred relative to the Control treatments, but not for the Lightly browsed treatments, indicating that the application of goats for woody species reduction needs to be at least as heavy as a 90% defoliation within the zone that goats can reach. Goat activity would also need to be applied over one or two short browsing events each year for at least 3 years. Both the Light and Heavy browsing intensities applied as treatments in this research design were intentionally conservative to reduce opportunity for environmental damage at this state-owned research site. Research conducted by Wood (1987) in Virginia and by Green (1980) in California resulted in a near elimination of brush cover after only 2 years of goat browsing, but the intensity of browsing was greater in those studies than in this research design, and it was comparable to the defoliation and debarking that is achieved by goat browsing contractors when they are hired to manage woody vegetation. Rathfon et al. (2014) rotated goats when they “depleted” the plot forage, which was described as “substantial to nearly complete defoliation of all shrub layer vegetation up to 2 meters (6 to 7 feet) tall. Defoliation occurred through grazing of leaf blades, browsing of stem growth, and in some cases debarking or breaking of small stems that resulted from horn rubbing. This study in Indiana applied 2 browsing events per treatment during the 1 year study and found very few significant changes caused by goat browsing in the vegetation survey the following May. A native woody species, *Lindera benzoin*, was reduced in height relative to the Control treatments, but the aggressive *Rosa multiflora* was not reduced in cover or height. The Rathfon et al. 2014 study results indicate that a single year of 2 defoliations is not sufficient to remove brush with goats. Goats in our research were not pushed to debark a large component of the woody vegetation prior to moving to a new paddock in the current study for fear of damage to soils and desired plant species. A repeat of this type of study in the Upper Midwest would benefit from a higher intensity treatment, such as 100% defoliation and goats pushed to debark stems, at least twice each growing season, for as many years as there were woody species to be removed or until sufficient herbaceous growth occurred for fire to be added as a management tool. Brush that are not desirable in the stand and that have foliage above 2.13 meters (7 feet) should be coppiced following the first browsing event to allow the goats to provide root reserve draining defoliation of the entire leaf production by the brush.

The herbaceous, non-woody, plant components of the research treatment did not have a large graminoid species cover or richness component at the start of the research, nor after 3 years of goat browsing. Forb cover and richness was greater than graminoids, and also showed the most impact, in Heavily browsed treatments relative to the Control treatments. This is a different result than found by Wood in West Virginia in 1987, and by Green in California in 1980, where forbs and graminoids increased after 2 years. The difference in goat browsing intensity of the WV and CA studies relative to our study, and the presence of an upper story of tree canopy that shaded much of current study treatment but was not a factor for the Wood or Green research.

Aggressive forb species cover (P = 0.0313) and richness (P = 0.0076) were the greatest increasers in the herbaceous species component of treatment changes, but no one particular species showed a significant increase in the Heavily browsed treatments over the Control or Lightly browsed treatments in 2014. There was a trend for an increase in both cover and richness for only 3 of the 20 species recorded. Those species were burdock (P = 0.070), common mullein (P = 0.055), and bull thistle (P = 0.060). This is expected and could be controlled in future years of goat browsing due to goat forage preferences being high for thistle and burdock, and by fire or exclusion by graminoids for common mullein. Over the last 10 years of personally applying goats for brush control, I have observed that goats will not eat common mullein, even when pushed to defoliate 100% of foliage and debark woody stems. Goats in the three years at this site were never recorded consuming common mullein. Other goat browsers that I've advised and worked with over these years have had the same personal observation of avoidance of this species by goats.

CONCLUSIONS

Oak savannas in the Upper Midwest have become ingrown with brush and saplings as both fire and historic browsers were removed. This change from an open to closed midstory has resulted in the loss of the sun-loving groundlayer as well as regeneration of oak. Fire is inadequate at removing woody growth, particularly clonal brush, in such conditions where grass litter is absent and the groundlayer is often moist. After 3 years of heavy goat browsing at a 90% foliage reduction woody species cover, height and living stem densities were significantly reduced by 28%, 0.44 m, and 43%, respectively. Forb richness and cover increased by 19% and 17%. Aggressive forbs were the group with the greatest increase and this would bear watching over a longer period of time to determine if such species persist and continue to expand. The majority of these species, burdock, common mullein, and bull thistle may be controlled in future years as goat forage preferences are high for upright forbs like thistle and burdock, and by fire or exclusion by graminoids. Litter depth, soil compaction and sunlight penetration did not differ significantly between treatments demonstrating that the Heavily browsed goat treatments over 3 years did not induce environmental damage. In savannas with a diversity of life forms, particularly taller plants that may extend beyond a goat's reach or species that are not palatable, supplemental management tools will be needed.

ACKNOWLEDGEMENTS

The authors express appreciation to our collaborators on the project, including Bruce Folley and Jackie Curry, WI DNR, YLWA land managers; Keefe Keeley and Rebecca Dymzarov, UW-Madison research technicians at the time of the study; Jesse and Jaye Bennett at Driftless Land Stewardship, LLC, Ben Robel at Vegetation Solutions, LLC and Cherrie and Lee Nolden at 1dr Acres Farm for supplying the goats in 2011, 2012 and 2013 respectively; Carl Fredericks, Grass Mapping Enterprises, LLC; Nicholas Keuler and Peter Crump, UW-Madison Statistics Consulting; and Lee Nolden for field research assistance. This research was funded in part by WI DATCP's Wisconsin Grazing Lands Conservation Initiative (GLCI) grant, North Central Region SARE graduate student grant, Animal Welfare Approved good husbandry grant, and UW-Madison CIAS graduate student grant, an Agroecology mini grant, and RAships from the UW-Madison Agroecology Program and Landscape Architecture Department.

CHAPTER 3:

Plant composition of meat goat diets and meat goat performance in an oak savanna in the Driftless Area of Wisconsin

C.A. Nolden, J.A. Harrington, J.A. Ela, K. Baumann

Department of Animal Sciences, University of Wisconsin-Madison, Madison, WI 53706, USA

Department of Landscape Architecture and Department of Agroecology, University of Wisconsin-Madison, Madison, WI 53706, USA

ABSTRACT

Increasing meat goat production in the Upper Midwest is helping meet the local demand by traditional goat meat consumers, but cost of production remains a challenge for producers. Coupling goat dietary preference for woody plants with managed goat production is a potential means to reduce cost of production while concurrently controlling woody aggressive plants. The removal of fire and native grazers, coupled with consequent shrub and tree encroachment, has resulted in oak savanna and woodland decline in the Upper Midwest. Restoring and maintaining these open structured communities can be difficult for private landowners on whose land the majority of these remnants occur. This presents an opportunity for exploring an unconventional restoration tool integrated with production of healthy meat for traditional and nontraditional goat meat consumers. Learning the diet

composition and time budgets of meat goats can facilitate their application as a restoration tool. This study looked at grain-free managed browsing of meat goats in a brush invaded oak woodland in southwest Wisconsin. We explored the performance of goats as measured by average daily weight gain (ADG), change in body condition score (BCS) and change in FAMACHA anemia score for an indication of negative gastrointestinal nematode effects. This study collected goat performance data from 3 herds of goats managed under two grazing regimes (Lightly browsed and Heavily browsed) in a five replicate block design study under a rotational grazing regime. The study observed goat browse selection and changes in goat weight and health by class and breed to measure goat productivity on this free forage source. Each treatment paddock was 0.5 ha (1.2 ac) and 6.4 animal unit equivalents of goats was rotated through twice in 2011 and 2012, and once in 2013. Plant species composition of the research site was conducted in June of 2011, 2012 and 2014. Goats were followed to record dietary selections and analyzed using Kulcyznski's Similarity Index. Goat diets averaged over 3 years were dominated by woody species (84% of the diet), followed by forbs (12%), and 3% selection for graminoids. The availability of those types of forages changed in the site over the duration of the study, but goats selected more woody species than would be predicted on availability alone, and selected less forb and graminoid forages than was available at the site. Goats spent the majority of their time eating woody species, -- grey dogwood (*Cornus racemose)* (13.5%), common prickly ash (*Zanthoxylum americanum)* (7.23%), American basswood (*Tilia Americana)* (6.44%), black raspberry (*Rubus occidentalis)* (6.16%), chokeberry (*Prunus virginiana)* (6.02%), and American elm (*Ulmus americana)* (5.13%) of the average goat diet at this site. Weight gain and body condition maintenance among kids exceeded expectations and levels of gastrointestinal nematode parasites were considered acceptable for meat production and goat health. Management of aggressive brush with goats provided a free, organic, high quality and abundantly available source of goat forage.

INTRODUCTION

Oak savanna is a highly diverse floral and faunal community that has declined to critical levels in recent times throughout its U.S. range. Its decline is due to the removal of fire and grazing. The result is an understory filled with shade-tolerant brush and a reduced diversity of habitats for wildlife species (Curtis, 1959; Nuzzo, 1986; Werner et al., 1990; Henderson & Epstein, 1995; Compton et al., 2003; Nowacki and Abrams, 2008). Restoration is expensive and time-consuming. Fire is commonly used to manage woody plants and litter buildup, but it can be ineffective in penetrating very dense vegetation with damp fuels (Compton et al, 2003; Nowacki and Abrams, 2008; Harrington and Kathol, 2009). Mechanical and herbicide treatments are options for shrub and sapling removal, but also fraught with challenges that result in low implementation (Magadlela et al., 1995; McCarron and Knapp, 2003; Heisler et al., 2004). In ecosystems dependent upon fire, additional tools are often needed as supplements or substitutes in situations where fire cannot be employed, as an initial treatment to allow fire in the future or as a more selective treatment between prescribed burns (Magadlela et al., 1995; McCarron and Knapp, 2003; Heisler et al., 2004). Rotationally browsed livestock have the potential to fill this role since they can be applied any time throughout a growing season, multiple times per season, and independently of weather (Hart, 2006; Papanastasis, 2009; Hart, 2012). Goats are an ideal species due to their greater dietary selection of browse relative to other types of forages (Elias and Tinschew, 2016).

Dietary Selection Discrimination

Goats have several characteristics that suit them well to vegetation management. Their most unique attribute is their dietary preference for browse over forbs and grasses. Goats readily eat thorny plants and have higher browse diets than the Scottish Highland cattle (Gordon, 1989), with a greater tolerance of tannins than cattle or sheep, and goats rarely bloat (Ela, 2012). According to Hart (2005), they are a low-input species of livestock, require a very small investment for start-up, have inexpensive maintenance, and require only a moderate level of labor for animal management. Goats are smaller and more mobile than Scottish Highland Cattle (Ela, 2012), with nimble lips and a propensity to browse while standing on their hind legs (Haenlein et al, 1992). Goats will climb brush and trees to reach desirable vegetation (Hart, 2006). Goats consume and digest seeds, reducing the viability and number of aggressive plant seeds (Harrington et al., 2011), and they strip the bark off thin-barked trees, resulting in girdling and plant death (Hart, 2006). The nutrients that are tied up in woody vegetation are made available to the ecosystem through goat digestion and deposition in the form of urine and feces (Hart, 2006). Goats are adapted to arid environments, thus they exhibit small size, low metabolic requirements and efficient use of water (Malan, 2000; Alexandre & Mandonnet, 2005).

Although goats have been used world-wide to control brush encroachment, application of goats for brush control in rotational browsing systems is a relatively new concept in the Upper Midwest. Goats have unique characteristics, dietary preferences and approaches to vegetation control that make them a feasible alternative tool to chemical or mechanical control of aggressive vegetation (Distel and Provenza, 1991). Goat browsing has been studied for woody fuel reduction, aggressive species management, pasture maintenance and ecosystem restoration in structurally similar ecosystems in the U.S. and globally (Strang, 1973; Batten, 1979; Tsiouvaras et al., 1989; Severson and Debano, 1991; Perevolotsky and Haimov, 1992; Torpy et al., 1993; Popay and Field, 1996; Haumann, 1999; Luginbuhl et al., 1999; Valderrábano and Torrano, 2000; Holst et al., 2004; Smart et al., 2006; Aharon et al., 2007; Celaya et al., 2010; Ascoli et al., 2013; Elias and Tischew, 2016). Reduction of the shrub canopy in midwestern grassland ecosystems has resulted in more light at the herbaceous groundlayer and enhanced availability of habitat for the growth of desirable sun-tolerant herbaceous species, particularly warm-season grasses (Heisler et al., 2004; Nowacki and Abrams, 2008; McGranahan, 2011).

Although goats are widely thought to eat anything, including tin cans, they are more selective in their dietary preferences than other ruminant species (Walker et al., 2006). Hart (2006) reports that the greatest factor influencing the food consumed by a goat is that which they have learned to eat from their mothers, with the second most important factor being the plant community that they consumed in their first year of life. Dietary preferences change with time of year and location, as the plant chemicals change with the weather and season, presumably impacting palatability (Hart, 2006). Browse preference also changes with availability, where goats alone preferred brush as 50% of their diet, but goats browsed after sheep had eaten the grass and forbs in a paddock selected brush as 70-90% of their diet (Sidahmed et al., 1981).

Unpublished data from a research project on the USDA Dairy Forage Research Center land at the Badger Army Ammunition Plant (BAAP) in Prairie du Sac, WI (Nolden, unpublished data) indicates that goats readily defoliate and strip bark on autumn olive (*Elaeagnus umbellata*), buckthorn (*Rhamnus cathartica*), prickly ash (*Zanthoxylum americanum*), box elder (*Acer negundo*), elderberry (*Sambucus canadensis*), mulberry (*Morus rubra*), hackberry (*Celtis occidentalis*), hophornbeam (*Ostrya virginiana*), young elm (*Ulmus* spp.) and young honeysuckle (*Lonicera tartarica*, *L. morrowii*, *L.* x bella). Woody species that are readily defoliated and the tips eaten include blackberry (*Rubus allegheniensis*), raspberry (*Rubus occidentalis*), gooseberry (*Ribes cynosbati*), multiflora rose (*Rosa multiflora*), and poison ivy (*Toxicodendron radicans*) (Nolden, unpublished data). Long-term browsing trials in Oklahoma found similar results, with the addition of years to kill the plants (Gipson, 2005). Blackberries were controlled in 3 years, eastern redcedar (*Juniperus virginiana*) in 2-5 years, honey locust (*Gleditsia triacanthos*) within 1-2 years, rose species (*Rosa* spp.) took 3 years, dogwoods in 2-3 years, wild plum (*Prunus americana*) in 3 years, sumac (*Rhus* spp.) in 2-3. Gipson (2005) and Nolden (unpublished data) noted that few herbaceous species are not eaten by goats, with common mullein (*Verbascum thapsus*) being the most notably avoided plant.

Time of year, stage of plant maturity, and region affects consumption of browse by goats (Mitchell, 1996). Forage qualities may influence the dietary preferences of goats. Many of the aggressive plants that goats consume contain medicinal properties due to secondary plant compounds that have been reported by a number of authors (Sheaffer et al., 1990; Barnhart 1994; Makkar et al., 2009; Brunetti and Jodarski, 2011). Brunetti and Jodarski (2011) also showed that many of the plants that goats prefer contain higher levels of protein than the common forages of alfalfa (*Medicago sativa*), orchardgrass (*Dactylis glomerata* L.), or bromegrass (*Bromus inermis*).

Factors Affecting Brush Control by Goats

Perryman et al. (1995) believe that the essence of plant damage by livestock does not lie as much in the timing of grazing applications as in the duration and intensity, however, Bryan, 1994) observed that timing did have an influence on plant damage, with spring browsing producing a greater negative impact on brush than browsing after August. Repeated brush defoliation depletes stored energy reserves, weakening and or killing brush (Gipson, 2005). Previous studies suggest that brushy plants must be browsed as least twice in a single growing season in order for the impact to be long-term (Davis et al. 1975, Hart 2006), so frequency is also an important factor. Stripping of bark by goats will kill woody vegetation greater than 2 meters tall (Mitchell, 1996).

Examples of Goat Browsing Effectiveness

In steep West Virginia terrain, an early-season stocking rate of 8-10 adult goats were applied to land covered 45% by multiflora rose (Bryan, 1994). Goats browsing reduced the brush cover to 15% in one season, whereas it took sheep three seasons to accomplish the same. The researchers noted seasonal effects, where browsing early in the year was effective, but browsing after August first was deemed to produce negligible impacts on the multiflora rose. It took the goats 5 years of repeated rotational browsing to kill 98% of the multiflora rose at the site.

Mitchell (1996) conducted research on goat stocking rates in Oklahoma for control of aggressive brush. He recommends one goat per 2.47 ha per percent brush cover (1 goat ac^{-1} % brush $cover^{-1}$) as a season-long stocking rate for brush control. By applying .6 goats per ha on 13 ha (1.5 goats ac^{-1} on 32 acres) with 43% brush cover, goats cleared all of the browse within two seasons. Applying .6 goats per ha on 9.7 ha (1.5 goats ac^{-1} on 24 acres) with 62% brush cover took more than two seasons to clear the brush.

Mitchell (1996) found that rotating goats is more effective than set-stocking for brush control in Oklahoma. When in a dense group that is rotationally browsed, goats provided more uniform brush removal and were healthier due to the diverse diet consumed by the animals. Management can be adaptive, with the animals being moved when the desired impact is obtained in a particular paddock. Mitchell noted that the percent of brush that recovers is reduced with each browsing event.

Data from the Upper Midwest on goat dietary preferences for the browse species present at degraded oak savanna sites, and their behavior when applied for brush control is not published. With this study we aimed to collect data on goat dietary selections in relation to the botanical composition of the research site.

Goat Performance on Browse

In order to consider the use of goats as a tool for ecological restoration, the animals need to demonstrate, at a minimum, a maintenance of health when being browsed on the aggressive brush. Metrics for health in goats include the rate of body weight gain of kids, body weight maintenance in adult goats, maintenance of body condition, and management of internal parasites. Very little research exists on the performance of goats in oak ecosystem brush control applications.

The average daily gain results from goat browsing at the BAAP (Nolden, unpublished data) averaged 0.20 lb/d with no supplemental energy or protein, but with an ad libitum salt/mineral supplement. Goats at the YLWA site did not receive supplemental energy or protein. Average rates of gain in the Western Maryland University Pasture-based Meat Goat Performance Test were 57.0 g/d (0.125 lbs/d) in 2011, 62.1 g/d (0.137 lb/d) in 2012, and 33.2 g/d (0.073 lb/d) in 2013, with the 2013 winning goat gaining 86.2 g/d (0.190 lb/d) (Schoenian, 2013). This test most closely matches the protocol we used at the YLWA of no grain, forage only, but the Maryland test was conducted on a tame grass/legume pasture rather than in a brushy paddock. The next most comparable data would be from the Oklahoma Forage-based Buck Test, where from 2007-2011 the average daily gain was 63 g/d (0.14 lb/d) (Penick, 2012; Langston University, 2016). These results are harder to compare to gains anticipated from goats grazed in the Upper Midwest since the Oklahoma protocol frequently included a protein supplement of DDGs. According to the Oklahoma researchers, an average daily gain in the range of 45.4 to 181.4 g/d (0.10 to 0.40 lbs/d) is considered excellent for meat goat kid growth on pasture (Langston University, 2016). Average rates of gain in the Oklahoma Forage-based Buck Test were 103.31 g/d (0.228 lbs/d) in 2011, 95.41 g/d (0.210 lb/d) in 2012, and 128.28 g/d (0.283 lb/d) in 2013 (Penik, 2012; Howard et al., 2013).

Goats are highly susceptible to gastrointestinal nematode parasites, especially the barberpole worm, *Haemonchus contortus* (Hart, 2006). Infested goats have lower growth rates, markedly reduced reproductive performance, and have higher rates of illness and death (Leite-Browning, 2006). Consequently, *H. contortus* may account for greatly reduced profits in a goat operation. The FAMACHA system was developed by South African scientists and veterinarians (Van Wyk and Bath, 2002) as a low-cost tool to assess clinical anemia by examining the color of the goat's lower eyelids and comparing it to a color-coded chart (Kaplan et al., 2004). The FAMACHA system is a scale of 1-5, with 1 being good membrane color (low *H. contortus* parasite level) and 5 being very pale and anemic due to high worm loads (Lewandowski, 2010). Deworming is recommended at 3 or higher (Kaplan et al., 2004), with acceptable FAMACHA scores between 1 and 3. Data from BAAP indicates that goats not receiving deworming treatments became more parasitized over the browsing season, but stayed within the acceptable scores (Nolden, unpublished data). Harrington et al. (unpublished data) had similar results, indicating that goat browsing does not cause unmanageable levels of detrimental parasites.

The objectives of this study were to apply rotational goat browsing at 2 intensity levels for 3 years in a degraded oak savanna and measure goat performance metrics of average daily gain, body condition score changes, FAMACHA score changes, and goat selection of forages at the research site relative to forage availability. This information would help goat producers and landowners and managers evaluate the potential of goats as a conservation tool in degraded oak savannas.

METHODS

The research site is located on a 12-hectare parcel within the Yellowstone Lake Wildlife Area (YLWA) in Lafayette County, Wisconsin. Lafayette County is part of the Driftless Area that covers southwest and western Wisconsin, with the YLWA site located in the Southwest Savanna region.

Sickley et al. (n.d.) described the 1930's presettlement vegetation of this region as a mix of prairie and deciduous hardwood forest with predominant tree species including bur oak (*Quercus macrocarpa)* and white oak (*Q. alba)* with some shagbark hickory (*Carya ovata)* and red oak (*Q. rubra)*. The study site is located on the steep slope between a ridge top and valley. Slopes on the site range from approximately 12% to 30% with the USDA soil survey showing a band of thin rocky soils in the middle of the slope (NRCS, 2011). Bedrock in the area is near the soil surface and is part of the St. Peter formation, composed of sandstone with some limestone and shale (Mudrey et al., 1982).

Bruce Folley is the Wisconsin DNR wildlife biologist who managed the YLWA since 1997. He recounted that the DNR acquired the parcel of land containing the study site in 1989, from a beef grazier. The land, at the time of purchase, was in poor condition due to being severely overgrazed, even though grazing activities had ceased some time before the purchase. The first habitat management activity at the site was a 2008 logging that selectively thinned the oak woodland to a 30% oak canopy, and a forestry mowing that same year (Ela, 2012).

The existing vegetation community is similar to many degraded oak savanna remnants. In the absence of fire and historical browsing pressures, the canopy filled in with mesic species such as American elm (*Ulmus americana)* and American basswood (*Tilia americana)* along with numerous shrub species that shaded the forb and graminoid community. The 2008 logging of the site selectively targeted individuals of mesic species leaving a canopy composed of 54% white oak and 14% bur oak individuals. Red oak, shagbark hickory, black walnut *(Juglans nigra)*, and American elm are also present. The anticipated result of the 2008 logging was successional invasion of shrubby growth, particularly common prickly ash, gray dogwood, honeysuckle (*Lonicera* x *bella)*, quaking aspen (*Populus tremuloides)* and blackberry.

Experimental Design

In 2011, a randomized complete block design (RCBD) with 5 replicates were located within the 12-hectare site. Each 1.5-hectare block was divided into three 100-meter by 50-meter paddocks (0.5 hectares). Paddocks were positioned in such a way that the steepest part of the slope occurred in the center of every paddock. Each paddock was randomly assigned a goat browsing treatment: Lightly browsed or Heavily browsed or a Control (no browsing). Paddocks were divided in half across goat browsing treatments with a split plot treatment of interseeding. One half of each paddock was randomly assigned and broadcasted with a native seed mix while the other half received no treatment. As interseeding was anticipated to affect goat browse selection discrimination at some time in the future goats were fenced within each half paddock. All block units were buffered with a 1.5-meter mowed swath.

The five blocks were positioned so that treatment and control paddocks were oriented up and down the hill, parallel to the slope and each individual block was located to face a single aspect. A site map showing the layout of the replicate blocks can be found in Figure 2. Block A faces west-south-west (250 degrees from north), B faces south-south-east (160 degrees), C faces approximately east (100 degrees, D faces west (270 degrees), and block E faces southwest (220 degrees).

The initial stocking rate in 2011 and 2012 was determined through consultation with Jesse Bennett, Driftless Land Stewardship, LLC, the 2011 goat provider, past studies from Australia, and recommendations from the western U.S.A. A stocking rate of 86 goats per 0.5-hectare unit was used during the 2011 and 2012 field season. The 2012 goats belonged to Ben Robel, Vegetation Solutions, LLC. Based on goat body weights and metabolic class (nursing doe, kid, non-nursing doe) I calculated the animal unit equivalents (AUEs) of the goats to be 6.4 AUEs each year. I supplied the goats used in 2013, which were smaller framed than those used in 2011 and 2012, so using a head count would not apply the same browsing pressure on the site as in 2013. I calculated that 110 of these smaller goats would equal 6.4 AUEs in 2013, matching the browsing pressure of the previous two seasons. Goats were concurrently browsed on both sections of a treatment paddock (split plot), with 3.2 AUEs in each section, and then rotated to the next. A full rotation through all five replicate blocks took 30 days in 2011 and 2012—5 2-day treatment sections plus 5 4-day treatment sections.

The goal was for goats to consume 90 percent of shrub foliage in the heavily browsed paddocks during a rotation. One-day and two-day treatments were used during the first rotation of 2011 but were insufficient to reduce the majority of foliage. Browsing treatment length was doubled to two- and four-day treatments for the second 2011 rotation. In 2011, the first rotation began June 8 and ended June 22; the second rotation began July 18 and ended August 17. During 2012 the first rotation began June 7, 2012 and ended July 7, 2012. In both years, each paddock was rested a total of 38 days before beginning the second to allow browsed shrubs to regrow leaves.

The 2- and 4-day browse treatments were maintained for the first rotation of the 2012 field season. A drought began near the end of the first rotation resulting in a 17.8 cm (7") precipitation deficit by the end of the summer (U.S. Drought Monitor, 2012). The drought limited the regrowth of leaves and the four-day heavy browse treatment was shortened to three days due to lack of forage for the goats during the second rotation. The second rotation began July 16, 2012 and ended August 10, 2012.

Goats were provided by a different goat producer in each year of the study. The producer determined which mineral supplement to provide to the goats (2011: SweetLix 16:8 MeatMaker goat mineral, 2012: Producer's Pride Range Mineral, and 2013: Purina Range Mineral) and no other supplement or treatment was provided to the goats while in the research paddocks.

Given the wet spring and subsequent summer drought in 2013, the delay of the Animal Care and Use Protocol approval, and the lack of regrowth following the initial browsing, only one rotation was conducted in 2013. The light browsing treatment was increased from two to three days, and the heavy browsing treatment was increased from four to five days in length in order to achieve the 50% and 90% defoliation benchmarks, respectively. The 2013 browsing started on July 1, 2013 and ended on August 11, 2013.

Data Collection Methods

Vegetation Cover for Diet Selections

Sampling occurred in spring of 2014, following protocols established in 2011. Permanent nested quadrats were used to collect cover data: 1-square-meter quadrats for herbaceous species; 5-square-meter circular quadrats for shrub and sapling density and height. These permanent quadrats were selected based on a stratified random design to account for the influence of slope. Each half paddock was divided into a 3 by 3 grid totaling nine sections. A quadrat was then located at random within each of the nine sections. Precautionary buffers equal to the distance at which shrub cover was measured (5 meters) were used when selecting quadrat location to ensure cover board readings would not overlap. The nail marking the quadrat was always positioned in the bottom left corner of the one by one-meter quadrat when facing uphill.

All quadrats were sampled for herbaceous species presence/absence and relative cover to assess availability of forages. Cover was visually estimated using six cover classes (0-5%; 5-25%; 25-50%; 50-75%; 75-95%; and 95-100%) in accordance with the Daubenmire method (Daubenmire, 1959). Six of the nine quadrat locations were randomly selected in 2011as the center of circular 5-square meter shrub quadrats. All trees within each paddock were identified, measured for DBH and mapped with a GPS to obtain tree density prior to treatments in 2011.

Sampling occurred twice during the 2011 and 2012 growing seasons, once in late-May to early-June to capture spring ephemerals prior to goat introduction for that growing season and once after the second goat rotation in mid-August to capture summer and fall blooming species post-treatment. Shrubs were also sampled at both times in order to assess the immediate impacts of goat browsing treatment as well as treatment timing and shrub recovery from early to late summer. Final sampling occurred once in 2014, throughout the month of June.

Goat Dietary Selection

In the summer of 2011, 2012 and 2013, goat dietary intake was monitored for 6 days randomly selected days spaced over the full rotation. Six random goats (3 in each half paddock) were each observed every 15 seconds for 5-minutes, 4 times throughout the day, for forage species and type (herb, shrub/tree foliage or twigs) consumed, and any other behaviors. The 4 times throughout the day were morning (0800), mid-day (1100), early afternoon (1400) and evening (1700).

Goat Production Performance Assessment

In 2012 and 2013, goat health was assessed using FAMACHA test scores, body condition scores and body weights. Each goat producer was previously trained in FAMACHA anemia scoring, which is done by assigning a number to the color of the inner eyelid, with good scores being low and poor scores being high, on a scale of 1-5. Body condition scoring was also conducted by the trained goat providers, with a scale of 1-5 correlating to the amount of fat and muscle on a goat, thin =1 and obese = 5. Goat producers also weighed the goats by running them across a livestock scale that they provided. All goat performance data was collected 24 hours before the start of browsing and after the browsing within 24 hours of goat removal from paddocks. Body weight change, body condition score change and parasite load change were used to assess overall goat health as well as weight gain in kids raised for meat.

DATA ANALYSIS

Goat Dietary Selection Analysis

Goat dietary selection recordings were summed by type of forage consumed (shrub, sapling, vine, bramble, forb, graminoid), and each type divided by the count of all recordings to assess the percent of each forage in the goat's diet. In order to evaluate the homogeneity of the forage types and species selected by the goats relative to their availability, along with goat behavior time budgets, we evaluated percentages of cover by species, percentages of cover by forage type (woody, forb, graminoid), and percentages of time spent in various activities (eating, walking, chewing, laying, mineral, standing, drinking) for each year using a linear mixed model (PROC MIXED, SAS Inst. Inc., Cary, NC). Goat was considered the experimental unit in each model. Class variables were year, block, treatment, and time. Models contained a term for year time and location, with block and treatment used as random terms. Models contained a term for place x year only because the interaction was significant at $P \leq 0.05$. The LSD test was used for multiple treatment comparisons using the LSMEANS statement of SAS 9.4 with letter grouping obtained using the SAS pdmix800 macro.

Kulcyznski's Similarity Index (KSI; Oosting, 1956) was applied to estimate selection discrimination exercised by the three goat herds (Ferreira et al., 2009). Kulcyznski's similarity index (KSI; $[(2c_i)/(a_i+b_i)] * 100$, where a_i=% basal cover of component i, b_i = % of component i detected in herbivore diets, and c_i=the lesser of a_i or b_i) was used to evaluate diet selection patterns for each goat herd in relation to botanical composition of pastures (Oosting, 1956). For the purposes of our analyses, we assumed that KSI values ≥ 80% indicated little or no discrimination (i.e., selection patterns were similar to plant availability), that KSI values between 21% and 79% indicated moderate discrimination, and that KSI values ≤ 20% indicated either strong preference for or avoidance of individual plant species. Preference and avoidance were distinguished from one another by comparing the proportion of goat diets composed of component i with basal cover of component i in paddocks. Goat forage selections relative to their availability for the KSI were evaluated using linear mixed models (PROC MIXED, SAS Inst. Inc., Cary, NC). Goat was the experimental unit in each model. Class variables included year, block, treatment, time and location. Models included year, treatment location, year x treatment, year x location and treatment x location, with block treated as a random variable. Least squares means were considered different when protected by a significant F-test ($P \leq 0.05$).

Before browsing and after browsing weight measurements for all goats were obtained to assess weight change, and analyzed using a paired t-test in SAS. Changes in weight as average daily gain (ADG), body condition scores (BCS) and FAMACHA were tested by class of goat (nursing does, kids, and non-nursing does) and were analyzed as completely randomized designs using mixed models (PROC MIXED, SAS Inst. Inc., Cary, NC). Goat was considered the experimental unit, individually identifiable by ear tags. For goat ADG data, class variables were breed, class and year. For goat BCS and FAMACHA data, class variables were class and year. Models contained terms for breed, class, year and 2 way interactions. The LSD test was used for multiple treatment comparisons using the LSMEANS statement of SAS 9.4 with letter grouping obtained using the SAS pdmix800 macro. For the different statistical tests, significance was declared at a P-value of ≤ 0.05, and a statistical trend was noted at a P-value of ≤ 0.10.

To place the YLWA goat kid growth data in context with data collected during those years in Maryland and Oklahoma, the effects of data set origin and year were assessed for average daily gain in goat kids as a linear mixed model (PROC MIXED, SAS Inst. Inc., Cary, NC). Goat was the experimental unit in each model. Class variables included place, year, and place x year. Models contained a term for place x year only because the interaction was significant at $P \leq 0.05$.

RESULTS

Goat Forage Preferences

Goats demonstrated a very high preference for woody vegetation, relative to forbs and grass, in their diet in both 2011 and 2012 (Figure 1). This result is a higher browse preference than reported by researchers in other regions of the USA.

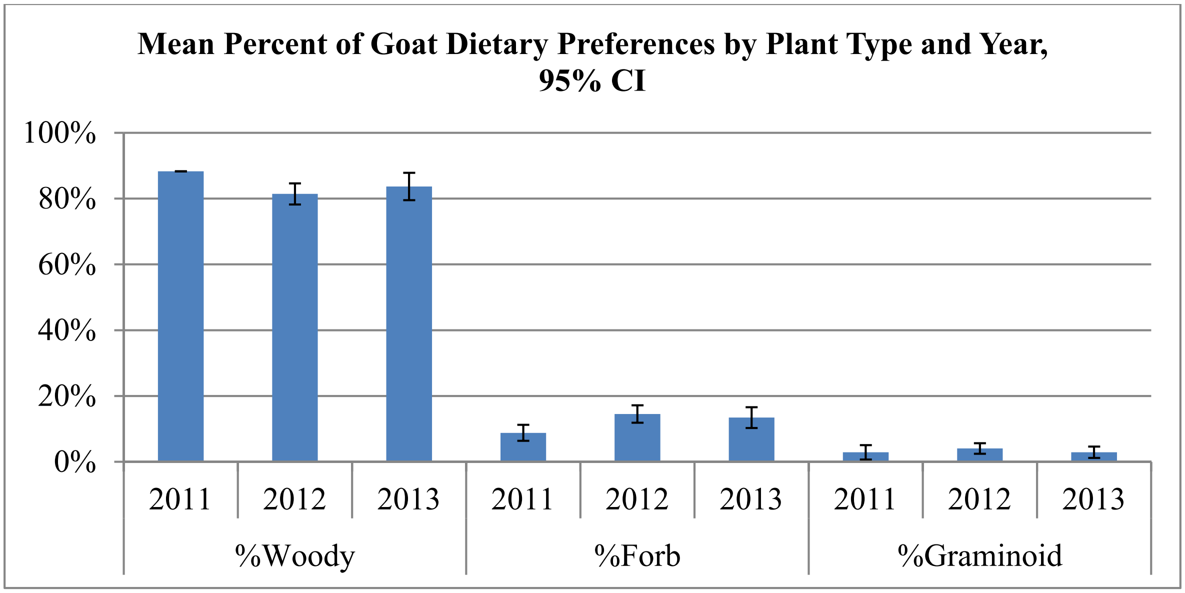


Figure 1. Goat dietary preferences by year and plant type. Goats, on average across the whole herd, gained profitable amounts of weight in all 3 years of the research with no significantly differences between years.

Goats can be divided into the stage of life classes of Kids, Nursing Does, Open Does, Yearlings and Wethers. These are known to have different average daily gains (ADG) and dry matter intakes. Kids are growing and eat more on a per weight basis than other classes. Nursing Does consume more than Yearlings or Open Does in order to produce milk. Wethers are neutered males that are in maintenance mode and have low dry matter intake and low weight gain. Table 1 in Appendix B shows significant differences ($p<.0001$) in the average daily weight gain of goats by year and class. Kids gained the most weight in all years, with exceptional gains in 2011 and 2012. Nursing does were statistically equivalent between years. Open does in 2012 lost significant amounts of weight, whereas they gained well in 2011 and 2013. Wethers maintained weight in 2011 and Yearlings gained weight in 2013.

The differences in weight in 2012 could be due to the weather, the mineral supplied to the goats, the breed of goats used that year, other factors, or a combination of these factors. 2012 was a drought year that likely impacted browse quality and quantity. The mineral used in 2012 contained 650 ppm copper, whereas the mineral in 2011 was 1800 ppm and in 2013 was 1200 ppm, so differences in mineral supplement could affect nursing doe weights. The goat owner in 2012 had a primarily Kiko herd, whereas the herds in 2011 and 2013 were more Boer and Myotonic, respectively. In 2012, the goat owner purchased new does just before the research began that were overweight from a grain-based diet, so those individuals were likely to lose weight in this brush-only foraging system.

Different breeds of meat goats are known for growth rate, muscling, and natural parasite resistance. Kiko goats tend to grow quickly and show parasite resistance but don't have as much muscle as Boers or Myotonics. Boers also grow quickly but tend to be susceptible to parasites. Myotonics are advertised as having a better meat:bone ratio than the other breeds, and Schoenian (2012) reported an 18% and 22.8% increase in yield of boneless, fat-free meat in two Myotonics above the average of all goats at the Maryland Pen vs Pasture Study. Myotonics also tend to be parasite resistant (Hart, 2006), but they grow slowly (Hayes, 2018) and tend to be smaller framed goats (Wang et al., 2017; Cherrie Nolden, personal experience).

Table 2 in Appendix B breaks out the YLWA research goats by their breed combination and class to show how these particular goats of these breeds performed on the brush-only diet at the research site. The Kiko kids significantly outperformed the Boer/Kiko mix kids and the Myotonic/Boer/Kiko kids in average daily gain (*P* <.0001), but the Kiko does didn’t maintain their weight as well as the other breeds. The kids and yearlings with Myotonic breeding didn’t perform significantly different from those with Boer/Kiko breeding.

Body condition scores (BCS) are a qualitative assessment of the muscle and fat cover that a goat carries over its lower back, ribs and sternum. Scores range from 1-5 with a score of 2.5-3 representing the ideal body condition, 1 = too thin and 5 = too fat. BCS was not collected in 2011. Table 3 in Appendix B shows that for most classes and years, goat BCS improved. Upon closer inspection, nursing does and yearlings lost significant body condition in 2012 and the same classes gained significant body condition in 2013.

Goats are especially susceptible to a parasite called the barber’s pole worm (*Haemonchus contortus*), which lodges in the abomasum and sucks blood out of the host goat to the point that the goat can die due to anemia. The parasites can survive over winter to infect goats the following season on an infected pasture/woodland and many populations of the parasite have developed resistance to chemical dewormers. The FAMACHA anemia scoring system uses the color of the inner eyelid to rank the level of anemia from 1 (pink and healthy) to 5 (creamy white and nearly dead). An increase in FAMACHA score is a bad indication for goat health. Deworming is recommended at 3.5 and above. Table 4 in Appendix B shows that the *H. contortus* parasite level was lower in kids in 2013 vs 2012, but 2011 goats were intermediate. None of the other classes or years had significant differences. We expected to see an increase in parasitism in 2012 and 2013 due to previous year pasture contamination. It is possible that the diversity of forages available in the brush-invaded savanna and their height off the ground was helpful to the goats in resisting *H. contortus*.

Meat Goat Time Budget

Goats were recorded in all of their activities during the 615 goat follows that were conducted over the 3 years. There were 2276 recordings of species consumed, and 1781 behavioral observations. Eating was the largest portion of the goat time budget. Percent time was calculated by dividing the number of recordings of a certain behavior by the total for all behaviors considered and observed.

Goats spent between 51% and 65% of their time eating, with significant differences in time between herds (Table 5 in Appendix B.) The 2012 herd spent significantly more time eating than the 2011 or 2013 herds ($P < .0001$). The eating time budget can be split into time spent eating brush, forbs and graminoids. Brush was between 45% and 54% of the activity budget of goats, with significantly more time spent eating brush by the 2012 herd relative to the 2011 herd ($P = 0.0033$). Time spent eating forbs ranged between 4% and 9% of the activity budget, with the 2011 herd spending less time eating brush than the 2012 or 2013 herds ($P < .0001$). Time spent eating graminoids ranged from 1.6% to 2.4% of the activity budget. The 2013 herd spent more time eating graminoids than the 2011 herd ($P = 0.0193$). Standing constituted the second largest use of time by the goats, with a range of 9.7%-26.4% of their time. Walking was the third largest component of the activity budget, with a range of 7%-10.7% of their time. Only time spent chewing was not significantly different between herds ($P = .5543$).

Table 6 in Appendix B shows the activity budget of the goats by time of day, with all herds averaged together. Percent of time is the number of observations of each activity divided by the total observations for each time of day. Goats spent most of their time eating in the early (63.7% of time) and late (61.1% of time) part of the day (P = .0021), avoiding the hot part of the day for activities (P = .0001). The goats ate forbs and graminoids equally throughout the day (P = .8206, P = .4724, respectively), while eating more brush in the mornings relative to the middle of the day (P = .0174), with evening brush consumption being intermediate.

Goat Selection of Forages Relative to Availability

Goats are selective browsers and had ad-libitum selection opportunities at the YLWA research site due to the study design moving goats once 50% of the vegetation had been consumed in the Lightly browsed treatments, and once 90% of the vegetation had been consumed in the Heavily browsed treatments. All three herds of goats demonstrated a high selection of woody vegetation, with forbs secondary and lower selection for graminoids.

Dietary selection, reported as % of diet, was calculated by dividing the number of observations of goats selecting the particular forage type by the total number of observations of goats eating. Table 7 in Appendix 3 shows the average percent of diet by species across all 3 years and forage types.

Dogwood was the most commonly consumed, followed by prickly ash, basswood, black raspberry, choke cherry, American elm, hazelnut (*Corylus americana*), aspen (*Populus tremuloides*), black cherry (*Prunus serotina*), gooseberry (*Ribes missouriense*), blackberry, and honeysuckle. Other species comprised less than 2% of the dietary selections of the goats. Common mullein was abundant on the site but goats were never observed consuming it in the 3 years of the study.

Dietary selection of woody species was greater in the 2011 herd than in the 2012 and 2013 herds (*P* < .0001), with 88.9% of the 2011 herd's diet comprising woody species, whereas there was no significant difference between the 2012 and 2013 herds, which consumed 81.2% and 83.8% of their diet as woody species, respectively. Average dietary botanical selection of woody vegetation across all three goat herds was 84.5% of the diet. The above results are summarized from Table 8 of Appendix B.

Dietary selection of forb species was greater in the 2012 and 2013 herds than in the 2011 goat herd (*P* < .0001), with the 2011 herd selecting 8.2% of their diet as forbs, and the 2012 and 2013 herds selecting 14.5% and 13.5% respectively. Average dietary botanical selection of forb species across all three goat herds was 12.2% of the diet.

Dietary selection of graminoid species was greater in the 2012 herd than in the 2011 and 2013 goat herd (*P* = 0.0355), with the 2012 herd selecting 4.3% of their diet as graminoids, and the 2011 and 2013 herds selecting 2.9% and 2.8% respectively (Table 8 of Appendix B). Average dietary botanical selection of graminoid species across all tree goat herds was 3.2% of the diet.

Forage and browse availability of woody, forb and graminoid species, as measured by cover at the quadrats in the Heavily browsed and Lightly browsed treatments, were significantly different by year (*P* < .0001, Table 8 of Appendix B). Woody species availability was greatest in 2012, less in 2013, and less in 2011, with percent of cover being 58.3%, 45%, and 39.2% in those three years, respectively ($P < .0001$). Forb availability and graminoid availability increased significantly with year, with both showing the smallest percent cover in 2011, more in 2012 and more in 2013. Forbs increased from 7.1% cover to 49.2% cover over that time, while graminoids increased from 2.1% cover to 13.7% cover over those years.

KSI was used to evaluate the level of discrimination adult goats exercised in selecting diet components. Data shown in Table 8 of Appendix B demonstrate that goats did not consistently select any of the forage types in proportion to their availability (i.e. KSI values ≥ 80%) in the brush-invaded oak savannas used in our experiments. Goats showed a moderate preference (i.e. KSI between 21% and 79%, selection frequency > availability) for woody species in all 3 years, with the selection being closer to in proportion with availability in 2012, less in 2013, and less in 2011 ($P < .0001$). Forb selection changed significantly from a strong preference in 2011 to a moderate preference in 2012, and to a moderate avoidance in 2013 ($P < .0001$). Goats showed a strong preference for graminoids in 2011, but a strong avoidance of graminoids in 2012 and 2013 ($P < .0001$).

Dietary Overlap of 3 Herds

Goat herds develop forage selection preferences based partly on the food culture of the herd. Each herd can be different in their selections of forages based on what they have eaten in the past and what other experienced herd mates choose to eat. There were differences detected among the three herds used in this research for their preferred forages (Table 9 in Appendix B) that weren't reflected in differential availability of those forages at the research site (Table 10 in Appendix B).

Dietary Discrimination of Meat Goats

Among the vegetation present in the YLWA research site browsing treatments, goat selection of forages was assessed with the use of 615 goat follows. Table 7 in Appendix B shows forage species selected by goats, ordered from those most selected by goats, down to those least selected, with the % of diet calculated by dividing the number of recordings of individual forage species selected by the total for all species selected.

Changes in Botanical and Abiotic Composition of Research Site

Pre-browsing vegetation surveys showed no significant differences between treatments. By the spring following 3 years of goat browsing, the heavily browsed treatment sites were significantly different than control sites in many of the vegetation response variables. By 2014, brush height and percent cover decreased, the number of dead woody stems was greater, herbaceous species richness and cover, specifically forbs, increased in Heavily browsed treatments than Control treatments. The goats caused no detectable difference in soil compaction or leaf litter reduction. Aggressive forbs as an entire category increased in Heavily browsed treatments, but no individual aggressive species showed significantly more cover relative to the Control treatments. The detailed description of these changes is in Chapter 2.

DISCUSSION

Goats selected woody vegetation as 80-90% of their diet in this study. Forbs were second in selection discrimination at 11% and grasses least selected at 2% of the diet. When consuming this forage-only diet as part of the study for controlling brush, goats gained weight well, gained or maintained body condition, and FAMACHA anemia scores did not rise more than a half a point. Across all years, goat kids at the YLWA gained an average of 114.4 g/d (0.25 lbs per day) on the brush-based diet, with individuals of the Kiko and Kiko/Spanish breeds gaining 145.15 g/d (0.32 lb/d) and 131.54 g/d (0.29 lb/d), respectively on average (Table 11, Appendix B). This growth rate was significantly better than the average daily gain reported for goats at the Western Maryland University Pasture-based Meat Goat Performance Test (Schoenian, 2013) and equivalent to goats at the Oklahoma Forage-based Buck Test (Penik, 2012; Howard et al., 2013) over the same three years (2011-2013), with average daily gains of 49.68 g/d in Maryland and 104.74 g/d in Oklahoma ($P < 0.0001$) (Appendix B, Table 11). There were differences by location and year, with 2013 showing significantly lower gains ($P < 0.0001$) at all locations relative to 2011 and 2012 (Appendix B, Table 12). The year by location interaction was significant ($P < 0.0001$), with goat kids at YLWA showing significantly greater growth rates than goat kids in Maryland in 2011 and 2012, a 45.3% and a 43.4% increased rate of gain at YLWA over Maryland for 2011 and 2012, respectively (Appendix B, Table 13).

From a business perspective, a 3.175 kg (7 lb) goat kid at birth on June 15 in the Upper Midwest would grow to an ideal market size of 25.86 kg (57 lb) in time for the ethnic Christmas market, when prices tend to be high, from browsing on brush of the quality that was available at the research site. At a reasonable market price of \$5.73 per kg live weight (\$2.60 per pound), this size goat would sell for \$148.20, which is a very good price for the low level of purchased inputs that were required to grow that goat to market weight relative to farmers raising goats on purchased grain and forages year-round, or pasture land with a mortgage.

A botanical composition of yearling steer and mature ewe diets in the Flint Hills (Sowers et al., 2019) showed a 65% dietary overlap between the ruminant species, with steers selecting 88% of their diet as graminoids and ewes selecting 58% as graminoids and 42% as forbs. Given the results of the goat dietary selection at our research site, goats would have the least dietary overlap with cattle, and less overlap with sheep than cattle have with sheep. Hedtcke et al. (2009) recorded that Scottish Highland cattle selected 42% of their diet as forbs, 31% as browse and 28% as grasses. This still pales in comparison to 84% of a goat diet being browse when livestock are being considered for application as a restoration tool and the site is primarily woody aggressive species. Based on the forage analyses done by Hedtcke et al. (2009) at the YLWA, the limitations of forage quality that resulted in unacceptable goat growth and maintenance on heather and poor quality available herbaceous species (*Pseudorrhenatherum longifolium* and *Agrostis curtisii*) in northwest Spain (Osoro et al., 2007) were not present at the YLWA research site since the goats in our research performed well. Merchant and Riach (1994) indicated that goats need forages with organic matter digestibility above 0.68, and Hedtcke et al. (2009) showed in-vitro true digestibility (IVTD) of forages across the site averaging 736 g kg^{-1}, which is equivalent to high quality alfalfa.

Goats in this study demonstrated a consistently higher intake of brush than most goat diet studies report (Papachristou and Nastis, 1993a and b; Raats et al., 1996; Papachristou 1997; Papachristou et al., 1997), but also showed differences in selections between herds and years. Arviv et al. (2016) showed that adult goats will eat 50% more of an item that they have been preconditioned to consume, and that their kids tended to show a greater preference for the species that their dams selected. All three herds of goats used for this research had been used for many years prior to the project for brush control in Wisconsin with a similar set of plant species. The 2012 herd included grain-fed goats that were added to increase the herd size for the study and those individuals did not have the experience of the others in that herd, so differences in forage selection for the 2012 year may have been influenced by those individuals.

Patrizi et al. (2018) detailed an emergy evaluation of an agro-livestock integration as a metric of sustainability, and the 33% savings of that particular integrated system instead of the two isolated production systems is likely a common feature of applying goats to control brush where it is considered a nuisance.

CONCLUSIONS

Managing goats intensively and as a tool for brush management at sites like the Yellowstone Lake Wildlife Area is a viable production approach for meat goats. The goats perform brush removal through their natural dietary selections, the market class of goat gains well on brush alone as their forage, the herd maintains or gains in body condition and doesn’t become more heavily parasitized by gastrointestinal nematode parasites. Goat dietary selections were dominated by woody species (84% of the diet), followed by forbs (12%), and 3% selection for graminoids. The availability of those types of forages changed in the site over the duration of the study, but goats selected more woody species than would be predicted on availability alone, and selected less forb and graminoid forages than was available at the site. Goats spent the majority of their time eating woody species, with *Cornus racemosa* making up 13.5% of the average goat diet from this site, followed by *Zanthoxylum americanum* (7.23%), *Tilia americana* (6.44%), *Rubus occidentalis* (6.16%), *Prunus virginiana* (6.02%), and *Ulmus americana* comprising 5.13% of the average goat diet. This distinct selection for woody species from three independently owned herds of goats, along with the lack of negative outcomes from the application of the herds in rotation for brush management, provides goat owners and land managers information to help them decide if goat browsing is a useful management tool for a particular site.

Acknowledgements

The authors express appreciation to our collaborators on the project, including Bruce Folley and Jackie Curry, WI DNR, YLWA land managers; Keefe Keeley and Rebecca Dymzarov, UW-Madison research technicians at the time of the study; Jesse and Jaye Bennett at Driftless Land Stewardship, LLC, Ben Robel at Vegetation Solutions, LLC and Cherrie and Lee Nolden at 1dr Acres Farm for supplying the goats in 2011, 2012 and 2013 respectively; Carl Fredericks, Grass Mapping Enterprises, LLC; Nicholas Keuler and Peter Crump, UW-Madison Statistics Consulting; and Lee Nolden for field research assistance. This research was funded in part by WI DATCP's Wisconsin Grazing Lands Conservation Initiative (GLCI) grant, North Central Region SARE graduate student grant, Animal

Welfare Approved good husbandry grant, and UW-Madison CIAS graduate student grant, an Agroecology mini grant, and RAships from the UW-Madison Agroecology Program and Landscape Architecture Department.

LITERATURE CITED

A Greener World. 2019. Goat Standards. Animal production standards for the Animal Welfare Approved certification program. Accessed September 10, 2019 at < https://agreenerworld.org/certifications/animal-welfare-approved/standards/goat-standards/>.

Abella, S. R. 2010. Thinning Pine Plantations to Reestablish Oak Openings Species in Northwestern Ohio. Environmental Management 46:391-403.

Abella, S.R., T.A. Schetter, T.L. Walters. 2018. Testing the hypothesis of hierarchical predictability in ecological restoration and succession. Oecologia 186:541-553.

Alexandre G. and N. Mandonnet. 2005. Goat meat production in harsh environments. Small Ruminant Research 60:53-66.

Anderson, R.C. 1998. Overview of midwestern oak savanna. Transactions of the Wisconsin Academy of Sciences, Arts, and Letters 86:1-18.

Anderson, R.C., and M. Bowles. 1999. Deep soil savannas and barrens of the Midwestern United States. Page 155-170 in R.C. Anderson, J.S. Fralish, and J.M. Baskin, editors. Savanna, Barrens, and rock outcrop plant communities of North America. Cambridge University Press, Cambridge, United Kingdom.

Apfelbaum, S.I. and A.W. Haney. 1991. Management of degraded oak savannah remnants in the upper Midwest: Preliminary results from three years of study. *In*, G.V. Burger, J.E. Ebinger, and G.S. Wilhelm (eds.), Proceedings of the Oak Woods Management Workshop. Eastern Illinois University, Charleston.

Arborist Site. 2009. Forestry Mowing. Online Discussion Forum: Accessed January 20, 2013. <http://www.arboristsite.com/forestry-logging-forum/107933.htm>.

Arviv. A. H.Muklada, J. Kigel, H. Voet, T. Glasser, L. Dvash, E.D. Ungar. 2016. Targeted grazing of milk thistle (*Silybum marianum*) and Syrian thistle (*Notobasis syriaca*) by goats: Preference following preconditioning, generational transfer, and toxicity. Applied Animal Behaviour Science 179:53-59.

Auclair, A.N. 1976. Ecological factors in the development of intensive-management systems in the Midwestern United States. Ecology 57:431-444.

Bailey, D.W. and J.R. Brown. 2011. Rotational grazing systems and livestock grazing behavior in shrub-dominated semi-arid and arid rangelands. Rangeland Ecology & Management 64:1-9.

Barnes, M.K., B.E. Norton, M. Maeno, and J.C. Malechek. 2008. Paddock size and stocking density affect spatial heterogeneity of grazing. Rangeland Ecology & Management 61:380-388.

Barnhart, S.K. 1994. Warm-Season Grasses for Hay and Pasture. Pm-569. Iowa State University Extension.

Barry, D.M. and R.A. Godke. 1978. The Boer goat: Potential for cross breeding. Department of Animal Science, LSU Agricultural Center. Louisiana State University, Baton Rouge, Louisiana. Accessed November 1, 2013. <http://www.boergoats.com/clean/articleads.php?art=23>.

Bath, G.F., J.W. Hansen, R.C. Krecek, J.A. Van Wyk, A.F. Vatta. 2001. Sustainable approaches for managing haemonchosis in sheep and goats. Final Report of Food and Agriculture Organisation (FAO), Technical Cooperation Project No. TCP/SAF/8821(A). FAO, Rome, Italy.

Batten, G.J. 1979. Controlling scrub weeds with goats. Proceedings of the 32nd New Zealand Weed and Pest Control Conference pp 292-296.

Baumann, K. 2013. Rotational goat browsing as a restoration tool for reducing midstory shrub density in oak savanna. Master's Thesis. University of Wisconsin-Madison, Madison, Wisconsin.

Beeden, J., and I. McIvor. 2010. The effects of pollarding on the fine roots of willows planted for soil stabilization on pastoral hill slopes. Report to contributing regional councils and MAF contract 23273. 1-7. Available at < http://www.poplarandwillow.org.nz/documents/effect-of-pollarding-on-fine-root-systems-of-willows.pdf>, accessed 6/15/2019.

Bory, G., M.D. Sidibe, D. Clair-Maczulajtys. 1991. Effets du recépage sur les réserves glucidiques et lipidiques du faux-vernis du Japon. Ailanthus glandulosa Desf, Simarubacées. Ann. Sci. For. 48:1-13.

Bowles, M.L. and J.L. McBride. 1998. Vegetation composition, structure, and chronological change in a decadent midwestern North American savanna remnant. Natural Areas Journal 18:14-27.

Brock, J.H. 1988. Livestock: Biological control in brush/weed management programs. Rangelands 10:32-34.

Brunetti, J. and G. Jodarski. 2011. Enhancing Organic Herd Health. Organic University Course #3 Handbook. Midwest Organic and Sustainable Education Services. Minneapolis, MN.

Bryan, W.B. 1994. Mechanical control of the multiflora rose. West Virginia University Extension Service. Accessed October 6, 2013 < http://www.wvu.edu/~agexten/pubnwsltr/TRIM/5420.htm>.

Campbell, E and C.A. Taylor. 2006. Targeted grazing to manage weedy brush and trees. In: Launchbaugh, K.; Walker, J., eds. Targeted grazing handbook. Centennial, CO: American Sheep Industry Association: pp 77-87.

Chavez, A.S. and E.M. Gese. 2005. Food habits of wolves in relation to livestock depredations in northwest Minnesota. American Midland Naturalist 154:253-263.

Cochrane, T.S. and H.H. Iltis. 2000. Atlas of the Wisconsin prairie and savanna flora. Wisconsin Department of Natural Resources, Madison, Wisconsin.

Compton, P., J. Hedtcke and J. Harrington. 2003. Integrating livestock production and conservation: Use of cattle in oak savanna restoration. Project Summary. UW-Extension Environmental Resources Center.

Curtis, J.T. 1959. The Vegetation of Wisconsin. University of Wisconsin Press, Madison, Wisconsin.

Daryanto, S., B. Fu, W. Zhao, and L. Wang. 2019. One-hundred years after shrub encroachment: Policy directions towards sustainable rangeland-use. Land Use Policy 84:71-78.

Daubenmire, R. 1959. A canopy-coverage method of vegetational analysis. Northwest Science 33:42-64.

Davis, G.G., L.E. Bartel, and C.W. Cook. 1975. Control of gambel oak sprouts by goats. Journal of Range Management 28:216-218.

Decagon Devices Inc. 2010. AccuPAR Model LP-80 Operator's Manual Version 10.

DICKEY-john Corporation. 1987. Soil Compaction Tester.

Decker, T. 2018. Targeted-grazing as a fuels reduction treatment: evaluation of vegetation dynamics and utilization levels. Masters of Science Thesis, Department of Wildland Resources. Utah State University.

Distel, R. A., and F. D. Provenza. 1991. Experience early in life affects voluntary intake of blackbrush by goats. Journal of Chemical Ecology 17:431-450.

McIvor, D.G., A. Manderson, T.M. Braaksma S, R. Gray. 2009. Effectiveness of space-planted trees for controlling soil slippage on pastoral hill country. In Nutrient Management in a Rapidly Changing World, L D Currie and C L Lindsay, editors. Occasional Report No. 22, pp 1-423.

Duckett, S.K., D.G. Wagner, L.D. Yates, H.G. Dolezal, S.G. May. 1993. Effects of time on feed on beef nutrient composition. Journal of Animal Sciences 71:2079-88.

El Aich, A., N. El Assouli, A. Fathi, P. Morand-Fehr, A. Bourbouze. 2007. Ingestive behavior of goats grazing in the Southwestern Argan (*Argania spinosa*) forest of Morocco. Small Ruminant Research 70:248–256.

Ela, J. 2012. Opportunities for livestock grazing and conservation: managed goat browsing in midwestern oak openings. Master's thesis. University of Wisconsin-Madison, Madison, Wisconsin.

Elias, D., and S. Tischew. 2016. Goat pasturing-A biological solution to counteract shrub encroachment on abandoned dry grasslands in Central Europe? Agriculture, Ecosystems and Environment 234:98-106.

Fajemisin, B., D. Ganskopp, R. Cruz, M. Vavra. 1996. Potential for woody plant control by Spanish goats in the sagebrush steppe. Small Ruminant Research 20:229–238.

Ferreira, L.M.M., R. Celaya, U. Garcia, MAM Rodrigues, K. Osoro. 2009. Differences between domestic herbivore species in alkane faecal recoveries and the accuracy of subsequent estimates of diet composition. Animal Feed Science and Technology 151:128–142.

Fleischner, T.L. 1994. Ecological costs of livestock grazing in western North America. Conservation Biology 8:629-644.

Freking, B. 2017. Oklahoma Forage-based Meat Goat Buck Test. Eastern Oklahoma State College. Accessed 9/10/19 at <https://www.eosc.edu/sites/www/Uploads/files/Discover%20EOSC/Farm/2017%20Buck%20Test/Buck_Test_2017.pdf>.

Fuhlendorf, S.D., F.E. Smeins and C.A. Taylor. 1997. Influence of tree size and browse history on understory relationships of Ashe juniper. Journal of Range Management 50:507-512.

Garcia, R.R., R. Celaya, U. Garcia, K. Osoro. 2012. Goat grazing, its interactions with other herbivores and biodiversity conservation issues. Small Ruminant Research 107:49-64.

Gipson, T.A. 2005. Meat Goat Production Handbook. Langston University Press. PO Box 730, Langston, Oklahoma.

Gleditsch J.M. and T.A. Carlo. 2011. Fruit quantity of invasive shrubs predicts the abundance of common native avian frugivores in central Pennsylvania. Diversity and Distributions 17: 244–253.

Google Maps. 2012. Yellowstone Wildlife Area, Darlington, Wisconsin.

Gordon, I.L. 1989. Vegetation community selection by ungulates on the Isle of Rhum. II. Journal of Applied Ecology 26:53-64.

Green, L.R. 1980. Goat browsing to control brush regrowth on fuelbreakes in southern California. P. 23. *In* Proc. Annu. Meet. Am. Soc. Range Manage., San Diego, CA 1980. American Society of Range Management, Portland, OR.

Griffin, T., W. Schacht, W. Fick, and P. Hain. 2005. Comparison of the growing point of grasses and forbs or woody species. Library of Crop Technology Lesson Modules. Accessed November 12, 2013, < http://forages.tennessee.edu/Page%208-%20Small%20Ruminant%20Practices.html>.

Haenlein, G.F., R. Caccese, and P.H. Sammelwitz. 1992. Goat Behavior. Extension Goat Handbook. National Agricultural Library. Accessed October 17, 2013. <http://www.boergoats.com/clean/articleads.php?art=45>.

Haney, A., M. Bowles, S. Apfelbaum, E. Lain, T. Post. 2008. Gradient analysis of an eastern sand savanna's woody vegetation, and its long-term responses to restored fire processes. Forest Ecology and Management 256:1560-1571.

Haney, A. and S.I. Apfelbaum. 1995. Characterization of Midwestern oak savannas. In F. Stearns and K. Holland, editors. Proceedings of the 1993 Midwest Oak Savanna Conference. Northeastern Illinois University, Chicago, Illinois, 20 February 1993. U.S. Environmental Protection Agency, Great Lakes National Program Office, Chicago, Illinois (available from http://www.epa.gov/glnpo/ecopage/upland/oak /oak93/haney.htm) accessed 18 June 2019.

Harrington, J.A. 1998. Grazing practices. Restoration and Management Notes 16:5-6.

Harrington, J.A. and E. Kathol. 2009. Responses of shrub midstory and herbaceous layers to managed grazing and fire in a North American savanna (oak woodland) and prairie landscape. Restoration Ecology 17:234-244.

Harrington, J.A. Personal communication with Cherrie Nolden on 8/12/2013.

Harrington, J.A., J.M. Ela and K. Baumann. 2011 & 2012. Unpublished data resulting from experimental goat browsing for oak savanna restoration at the Yellowstone Lake Wildlife Area in Blachardville, Wisconsin.

Harrington, K.C., W.B. Beskow, and J. Hodgson. 2011. Recovery and viability of seeds ingested by goats. New Zealand Plant Protection 64:75-80.

Hart, S.P. 2005. Goats for Vegetation Management. Meat Goat Production Handbook. Langston University Extension pp 223-233.

Hart, S.P. 2006. Goats for vegetation management. Langston University Extension E (Kika) de la Garza Institute for Goat Research. Accessed January 20, 2013. <http://www.luresext.edu/goats/training/vegetation.pdf>.

Hart, S.P. 2012. Vegetative Control. Cornell Sheep and Goat Symposium. Accessed October 5, 2013. < http://www.ansci.cornell.edu/goats/CSGSymposium/ vegetative_control_hart.pdf>.

Haumann, P., 1999. Biotope conservation with ruminants in Germany: the example of goats on shrub-infested slopes. In: Laker, J.P., Milne, J.A. (Eds.), Livestock Production in the European less favoured areas: meeting future economic environmental and policy objectives through integrated research. Proceedings of the 2nd International Conference of the LSIRD network pp 155–161.

Hayes, E. 2018. Influence of creep feeding on kid growth and dam health in multiple meat goat breeds and their crosses. Master's Thesis. Tennessee State University Department of Agricultural Sciences. Nashville, TN. pp 1-47.

Heavy Equipment Forums. 2009. Clearing land: would a forestry chipper be effective? Online Discussion Forum: Accessed January 20, 2013. <http://www.heavyequipmentforums.com/showthread.php?15011-clearing-land-would-a-forestry-chipper-be-cost-effective>.

Hedtke, J., J. Posner, M. Rosemeyer, K. Albrecht. 2009. Browsing for conservation: springtime forage value of midstory shrubs of degraded oak savannas in southern Wisconsin. Renewable Agriculture and Food Systems 24:293-299.

Heisler, J.J. Briggs, A. Knapp, J. Blair, and A. Seery. 2004. Direct and indirect effects of fire on shrub density and aboveground productivity in a mesic grassland. Ecology 85:2245-2257.

Henderson, R. 1995. Wisconsin's biodiversity as a management issue: Oak Savanna Communities, a report to Department of Natural Resource managers, Wisconsin Department of Natural Resources, Madison, Wisconsin. Pp 88-96.

Henderson, R. 1998. To graze or not to graze? Restoration and Management Notes. 16:6-7.

Henderson R. and E. Epstein. 1995. Oak Savannas in Wisconsin. Our living resources: a report to the nation on the distribution, abundance and health of U.S. plants, animals and ecosystems. U.S. Department of the Interior, National Biological Service, Washington, D.C. pp 230-232.

Holst, P.J., C.J. Allan, M.H. Campbell, A.R. Gilmour. 2004. Grazing of pasture weeds by goats and sheep. 2. Scotch broom (*Cytisus scoparius* L.). Aust. J. Exp. Agric. 44:553–557.

Howard, B., E. Woods, T. Johnson, C. Hofegartner, C. Rice, J.J. Jones, B. Freking, D. Husley. 2013. 2013 Buck Test. Eastern Oklahoma State College. Accessed 9/10/19 at < https://www.eosc.edu/discover_eosc/eosc_farm/2013_buck_test_results.aspx >.

Johnston, A. and R.W. Peake. 1960. Effect of selective grazing by sheep on the control of leafy spurge (*Euphorbia esula* L.). Journal of Range Management. 13:192-195.

Kaplan R.M., J.M. Burke, T.H. Terrill, J.E. Miller, W.R. Getz, S. Mobini, E. Valencia, M.J. Williams, L.H. Williamson, M. Larsen, A.F. Vatta. 2004. Validation of the FAMACHA eye color chart for detecting clinical anemia in sheep and goats on farms in the southern United States. Vet Parasitol. 123:105-120.

Kleppel, G.S. and E. LaBarge. 2011. Using sheep to control purple loosestrife (*Lythrum salicaria*). Invasive Plant Science and Management 4:50-57.

Knight, K. S., J. S. Kurylo, A. G. Endress, and J. R. Stewart. 2007. Ecology and ecosystem impacts of common buckthorn (*Rhamnus cathartica*): a review. Biol. Invasions 9:925-937.

Kochenderfer, J.D., J.N. Kochenderfere, and G.W. Miller. 2012. Manual herbicide application methods for managing vegetation in Appalachian hardwood forests. Newton Square, PA. United States Forest Service, Report NRS-96.

Lafleur, N.E., M.A. Rubega, and C.S. Elphick. 2007. Invasive Fruits, Novel Foods, and Choice: An Investigation of European Starling and American Robin Frugivory. The Wilson Journal of Ornithology 119:429-438.

Langston University, 2016. Oklahoma Buck Test Results. 1999-2010. Accessed 9/10/2019 at <http://www.luresext.edu/?q=content/buck-test-results>.

Launchbaugh, K, editor. 2006. Targeted grazing: a natural approach to vegetation management and landscape enhancement. American Sheep Industry Association. Cottrell Printing, Centennial, CO, USA.

Leite-Browning, M.L. 2006. *Haemonchus contortus* (Barber pole worm) infestation in goats. Alabama Cooperative Extension System. UNP-0078. Alabama A&M and Auburn Universities. Accessed November 1, 2013 < http://www.aces.edu/pubs/docs/U/UNP-0078/index2.tmpl>.

Lewandowski, R. 2010. Use FAMACHA Correctly. Accessed December 10, 2012. <http://sheep.osu.edu/2010/06/16/373/>.

Lopez-Bote, C.J., R.Sanz Arias, A.I. Rey, A. Castano, B. Isabel, J. Thos. 1998. Effect of free-range feeding on omega-3 fatty acids and alpha-tocopherol content and oxidative stability of eggs. Animal Feed Science and Technology 72:33-40.

Luginbuhl, J.M. 1998. Gastrointestinal Parasite Management of Meat Goats. NC Cooperative Extension Service. Accessed December 9, 2012. < http://www.cals.ncsu.edu/an_sci/extension/animal/meatgoat/MGWormer.htm>.

Lyons, R.K. and C.W. Hanselka. 2001. Grazing and Browsing: How Plants are Affected. B-6114. AgriLIFE Extension, Texas A&M. Accessed November 13, 2013, < http://repository.tamu.edu/bitstream/handle/1969.1/87088/pdf_1523.pdf?sequence=1 >.

Lyons, R.K., T.D.A. Forbes and R. Machen. 1996. What Range Herbivores Eat, and Why. Texas Agricultural Extension Service, College Station, Texas.

Mack, R.N. 2003. Plant naturalizations and invasions in the eastern United States: 1634-1860. Annals of the Missouri Botanical Garden 90:77-90.

Magadlela, A.M., M.E. Dabaan, W.B. Bryan, E.C. Prigge, J.G. Skousen, G.E. D'Souza, B.L. Arbogast and G. Flores. 1995. Brush clearing on hill land pasture with sheep and goats. Journal of Agronomy & Crop Science 174:1-8.

Makkar, H.P.S., T. Norvsambuu, S. Lkhagvatseren & K. Becker. 2009. Plant Secondary Metabolites in some Medicinal Plants of Mongolia Used for Enhancing Animal Health and Production. Tropicultura 27:159-167.

Malan S.W. 2000. The improved Boer goat. Small Ruminant Research 36:165-170.

Malan, F.S., J.A. Van Wyk, C.D. Wessels. 2001. Clinical evaluation of anaemia in sheep: early trials. Onderstepoort J. Vet. Res. 68:165-174.

Marcora, P.I., A.E. Ferreras, S.R. Zeballos, G. Funes, S. Longo, C. Urcelay, P.A. Tecco. 2018. Context-dependent effects of fire and browsing on woody alien invasion in mountain ecosystems. Oecologia 188:479-490.

McCarron, J.K. and A.K. Knapp. 2003. C3 shrub expansion in a C4 grassland: positive post-fire responses in resources and shoot growth. American Journal of Botany 90:1496-1501.

McGranahan, D.A. 2011. Species richness, fire spread, and structural heterogeneity in tallgrass prairie. Dissertation. Iowa State University, Ames, Iowa.

McIver, J., A. Youngblood, S.L. Stephens. 2009. The national Fire and Fire Surrogate study: ecological consequences of fuel reduction methods in seasonally dry forests. Ecological Applications 19:283-284.

McMahon, L.R., T.A. McAllister, B.P. Berg, W. Majak, S.N. Acharya, J.D. Popp, B.E. Coulman, Y. Wang, and K.J. Cheng. 2000. A review of the effects of forage condensed tannins on ruminal fermentation and bloat in grazing cattle. Can. J. Plant. Sci. 80:469–485.

Merchant, M. and D.J. Riach. 1994. The intake and performance of cashmere goats grazing sown swards. Grass and Forage Science. 49:429-437.

Mitchell, E.R. 1996. Brush Control with Goats. The Kerr Center for Sustainable Agriculture, Inc., Poteau, OK. Accessed August 8, 2013 < http://www.kerrcenter.com/publications/brushcontrol_goats.html>.

Monroe Municipal. 2019. Precipitation Data. Downloaded from: https://www.wunderground.com/history/monthly/us/wi/monroe/KEFT/date/2011-7 , accessed on 1/1/2019. Monroe Municipal, Monroe, Wisconsin.

Mosely, J.C. 1996. Prescribed sheep grazing to suppress cheatgrass: a review. Sheep & Goat Research Journal 12:74-81.

Mudrey, J.M., B.A. Brown, and J.K. Greenberg. 1982. Bedrock Geologic Map of Wisconsin. University of Wisconsin-Extension and the Geological and Natural History Survey.

Nolden, C.A. 2011-2013. Unpublished data. Brush control with goats at the Badger Army Ammunition Plant, USDA Dairy Forage Research Farm, Prairie du Sac, Wisconsin.

Nolden, C.A. 2014. Portable cold-weather goat shelter development and testing: goat preference testing of shelter cover type and deck number. 2015 Progress Report. North Central Region SARE Database, Farmer-Rancher grant number NCR-SARE FNC14-966. Accessed September 10, 2019 at < https://cdn.sare.org/wp-content/uploads/20171204130933/996260rvsd-for-mysare-nolden-2014-goat-shelter-annual-prg-rpt2.pdf>.

Nolden, C.A. 2015. Portable cold-weather goat shelter development and testing: Goat density preference testing. 2015 Progress Report. North Central Region SARE Database, Farmer-Rancher grant number NCR-SARE FNC14-966. Accessed September 10, 2019 at < https://cdn.sare.org/wp-content/uploads/20171204130933/10074632015-progress-report.pdf>.

NARSC, National Applied Resource Sciences Center. 1999. Sampling vegetation attributes: interagency technical reference. Bureau of Land Management.

NRCS, Natural Resources Conservation Service. 2011. Web Soil Survey. Accessed October 14, 2012. <http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx>.

Nowacki, G.J. and M.D. Abrams. 2008. The demise of Fire and "Mesophication" of Forests in the Eastern United States. Bioscience 58:123-138.

Nuzzo, V.A. 1986. Extent and status of Midwest oak savanna: presettlement and 1985. Natural Areas Journal 6:6-36.

O'Connor, R.P. 2006. A Land Managers Guide to Prairies and Savannas in Michigan: History, Classification, and Management. Lansing, Michigan.

Oosting, H.J., 1956. The study of plant communities: an introduction to plant ecology. W. H. Freeman and Company, San Francisco, CA, USA.

Osoro, K., L.M.M. Ferreira, U. García, B.M. Jáuregui, A. Martínez, R. Rosa García, R. Celaya. 2013. Diet selection and performance of sheep and goats grazing on different heathland vegetation types. Small Rumin. Res. 109:119–127.

Packard, S. 1988. Just a few oddball species: restoration and the rediscovery of the tallgrass savanna. Restoration and Management Notes 6:13-20.

Papachristou, T.G. 1997. Foraging behavior of goats and sheep on Mediterranean kermes oak shrublands. Small Rumin. Res. 24:85-93.

Papachristou, T.G. and A.S. Nastis. 1993a. Diets of goats grazing oak shrublands of varying cover in northern Greece. J. Range Manage. 46: 220–226.

Papachristou, T.G., and A.S. Nastis. 1993b. Nutritive value of diet selected by goats grazing on kermes oak shrublands with different shrub and herbage cover in Northern Greece. Small Rumin. Res. 12:35–44.

Papachristou, T.G., and V.P. Papanastasis. 1994. Forage value of Mediterranean deciduous woody fodder species and its implication to management of silvo-pastoral systems for goats. Agroforestry Syst. 27:269–282.

Papachristou, T.G., P.D. Plastis, V.P. Papansastasis. 1997. Forage production and small ruminant grazing responses in Mediterranean shrublands as influenced by the reduction of shrub cover. Agroforestry Systems 35:225-238.

Papachristou, T.G., L.E. Dziba, and F.D. Provenza. 2005. Foraging ecology of goats and sheep on wooded rangelands. Small Ruminant Research 59:141-156.

Papanastasis, V.P. 2009. Restoration of degraded grazing lands through grazing management: can it work? Restoration Ecology 17:441-445.

Patrizi, N., V. Niccolucci, C. Castellini, F.M. Pulselli, S. Bastianoni. 2018. Sustainability of agro-livestock integration: Implications and results of Emergy evaluation. Science of the Total Environment 622-623:1543-1552.

Peacock, C. and D.M. Sherman. 2010. Sustainable goat production. Some global perspectives. Small Rumin. Res. 89:78–80.

Penick, M. 2012. Oklahoma Forage-Based Buck Test: Summary Report: First 5 years (2009-2011). Kerr Center for Sustainable Agriculture. Kerr Center Goat Project. Accessed 9/10/19 at <https://kerrcenter.com/wp-content/uploads/2014/04/Goat-Summary-report-2011.pdf>.

Perevolotsky, A. and Y. Haimov. 1992. The effect of thinning and goat browsing on the structure and development of Mediterranean woodland in Israel. Forest Ecology and Management 49:61-74.

Perryman, B.L., W.A. Laycock, L.B. Bruce, K.K. Crane, and J.W. Burkhardt. 1995. Range readiness is an obsolete management tool. Rangelands 27:36-41.

Pierce, J.R., 1987. The use of goats for control of saffron thistle, *Carthamus lanatus* L. Proc. Aust. Weeds Conf. 8:31-34.

Popay, I. and R. Field. 1996. Grazing animals as weed control agents. Weed Technology 10:217-231.

Pruka, B.W. 1994. Distribution of understory plant species along light and soil depth gradients in an upland oak savanna remnant in southern Wisconsin. M.S. Thesis (Land Resources), University of Wisconsin, Madison. 271 pp.

Rahmann, G., 2000. Biotoppflege als neue Funktion und Leistung der Tierhaltung—dargestellt am Beispiel der Entbuschung von Kalkmagerrasen durch Ziegenbeweidung. Schrift.-R. Agraria 28:1–384.

Ratajczak, Z., J.B. Nippert, J.C. Hartman, and T.W. Ocheltree. 2011. Positive feedbacks amplify rates of woody encroachment in mesic tallgrass prairie. Ecosphere 2:1-14.

Rathfon, R.A., S. Fei, J. Tower, K. Andries, M. Neary. 2014. Prescribed grazing for management of invasive vegetation in a hardwood forest understory. In: Groninger, John W.; Holzmueller, Eric J.; Nielsen, Clayton K.; Dey, Daniel C., eds. Proceedings, 19th Central Hardwood Forest Conference; 2014 March 10-12; Carbondale, IL. General Technical Report NRS-P-142. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station pp 220-232.

Rayer, A. 2012. International meat review: livestock, poultry and grain market news. Des Moines, Iowa. United States Department of Agriculture Agricultural Marketing Service: Report 16:20.

Rayer, A. 2013. International meat review: livestock, poultry and grain market news. Des Moines, Iowa. United States Department of Agriculture Agricultural Marketing Service: Report 17:3.

Romme, W.H., M.G. Turner, G.A. Tuskan, R. Reed. 2005. Establishment, persistence, and growth of aspen (*Populus tremuloides*) seedlings in Yellowstone National Park. Ecology 86:404-418.

SAPPLPP. 2014. FAMACHA: An Eye-Colour Based Ready Reckoner for Assessing Worm-load in Small Ruminants. Accessed September 2019. <http://www.sapplpp.org/goodpractices/smallruminants/famacha-an-eye-colour-based-ready-reckoner-for-assessing-worm-load-in-small-ruminants.html#.XYJzE2lKhPY>.

Savanna Oak Foundation, Inc. (n.d.). Oak Savannas: Characteristics, Restoration, and Long-Term Management. Accessed September 6, 2013. <http://oaksavannas.org/>.

Schafer, R. 2013. Multi-species grazing with beef cattle and meat goats. South Dakota Pasture and Range Livestock Production Blog. Accessed November 11, 2013 <http://sdpastureandrangelivestockproduction.blogspot.com/2010/12/multi-species-grazing-with-beef-cattle.html?showComment=1384376408712#c3485217064904375873>.

Schier, G.A. and A.D. Smith. 1979. Sucker regeneration in a Utah aspen clone following clearcutting, partial cutting and girdling. USDA Forest Service Intermountain Forest and Range Experiment Station Res. Note INT-253.

Schoenian, S. 2012. Western Maryland Pasture-Based Meat Goat Performance Test. Accessed September 10, 2019. < https://www.sheepandgoat.com/2012-pen-vs-pasture>.

Schoenian, S. 2013. Western Maryland Pasture-Based Meat Goat Performance Test. Accessed November 11, 2013. <http://mdgoattest.blogspot.com/>.

Severson, K.E. and L.F. Debano. 1991. Influence of Spanish goats on vegetation and soils in Arizona chaparral. Journal of Range Management 44:111-117.

Sharrow, S.H., W.C. Leininger, B. Rhodes. 1989. Sheep grazing as a silvicultural tool to suppress brush. Journal of Range Management. 42: 2-4.

Sheaffer, C.C., G.C. Marten, D.L. Rabas, N.P. Martin and D.W. Miller. 1990. Reed Canarygrass. Minnesota Agricultural Experiment Station. SB- 595.

Sheuyange, A., G. Oba, R.B. Weladji. 2005. Effects of anthropogenic fire history on savanna vegetation in northeastern Nambia. Journal of Environmental Management 75:189-198.

Sickley, T.A., D.J. Mladenoff, V.C. Radeloff, and K.L. Manies. A Pre-European Settlement Vegetation Database for Wisconsin. Accessed November 11, 2013. < http://proceedings.esri.com/library/userconf/proc00/professional/papers/ pap576/p576.htm>.

Sidahmed, A.E., J.G. Morris, and S.R. Radosevich. 1981. Summer diet of Spanish goats grazing chaparral. Journal of Range Management 34:33-35.

Singh, D. and C.P. Swarnkar. 2012. Evaluation of targeted selective treatment strategy in sheep farm of Rajasthan. The Indian Journal of Animal Sciences 82:679–686.

Siscovick, D.S., T.E. Raghunathan, I. King, S. Weinmann, K.G. Wicklund, J. Albright, V. Bovbjerg, P. Arbogast, H. Smith, L.H. Kushi. 1995. Dietary Intake and Cell Membrane Levels of Long-Chain n-3 Polyunsaturated Fatty Acids and the Risk of Primary Cardiac Arrest. JAMA 274:1363-1367.

Simopolous, A.P. and J. Robinson. 1999. The Omega Diet. HarperCollins. New York.

Smart, A.J., Daniel, J., Bruns, K., Held, J., 2006. Browsing of western snowberry by goats and sheep. Sheep Goat Res. J. 21:1–5.

Solaiman, S.G. 2007. Simply Meat Goats. Tuskegee University Publication No. 115-1006.

Solecki, M.K. 1997. Controlling invasive plants. Pages 251-278 in S. Packard and C.F. Mutel, editors. The tallgrass restoration handbook. Island Press, Washington, D.C.

Sowers, C.A., G.A. Gatson, J.D. Wolf, W.H. Fick, K.C. Olson. 2019. Botanical composition of yearling-steer and mature-ewe diets in the Kansas Flint Hills. Rangeland Ecology and Management 72:126-135.

Stavi, I., D. Barkai, Y. Knoll, E. Zaady. 2017. Livestock grazing impact on soil wettability and erosion risk in post-fire agricultural lands. Sci. Total Environ. 573:1203–1208.

Staffen, A. 2010. Oak savanna state natural area management guide. Wisconsin Department of Natural Resources.

Strang, R.M., 1973. Bush encroachment and veld management in South-central Africa: the need for a reappraisal. Biol. Conserv. 5:96–104.

Taft, J. B. 1997. Savanna and open-woodland communities. Pages 24-54 in M.W. Schwartz, editor. Conservation in highly fragmented landscapes. Chapman and Hall, New York.

Teague, W.R., S.L. Dowhower, S A. Baker, N. Haile, P.B. DeLaune, and D.M. Conover. 2011. Grazing management impacts on vegetation, soil biota and soil chemical, physical and hydrological properties in tall grass prairie. Agriculture, Ecosystems & Environment 141:310-322.

Thomas, D.L. 2013. Personal communication with Cherrie Nolden on 1/30/2013 and 2/6/2013. Department of Animal Sciences, University of Wisconsin-Madison, Madison, Wisconsin.

Torpy, C.M., S.J. Muir, G.J. Melville and K.I. Fraser. 1993. Integrated control of the shrub *Dodonaea attenuata* based on goat grazing and herbicide application. In Proceedings II of the 10th Australian Weeds Conference and 14th Asian Pacific Weed Science Society Conference. Brisbane, Australia. pp, 6-10.

Towne, E.G., D.C. Hartnett, R.C. Cochran. 2005. Vegetation trends in tallgrass prairie from bison and cattle grazing. Ecological Applications 15:1550-1559.

Trimble, S. W. and A. C. Mendel. 1995. The cow as a geomorphic agent - A critical review. Geomorphology 13:233-253.

Tsiouvaras, C.N., N.A. Harlik, and J.W. Bartolome. 1989. Effects of goats on understory vegetation and fire hazard reduction in a coastal forest in California. Forest Science 35:1125-1131.

Urbanek, R. E., C. K. Nielsen, G.A. Glowacki, T.S. Preuss. 2012. White-tailed deer (*Odocoileus virginianus* Zimm.) herbivory in herbaceous plant communities in northeastern Illinois. Natural Areas Journal 32:6-14.

USDA-Forest Service (FS). 2012. Field Guide for Managing Tree-of-heaven in the Southwest. TP-R3-16-9. Accessed November 13, 2013. < http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5410131.pdf >.

USDA NASS. 2019. Sheep and Goats Final Estimates 2014-2018 (May 2019). National Agricultural Statistics Service. Bulletin Number 1056. < https://downloads.usda.library. cornell.edu/usda-esmis/files/6d56zw601/gh93h721n/qz20t179c/shgtsb19.pdf> accessed 7/1/19.

U.S. Drought Monitor. 2012. Accessed December 4, 2012. <http://droughtmonitor.unl.edu/DM_state.htm?WI,MW>.

Valderrábano, J. and L. Torrano. 2000. The potential for using goats to control *Genista scorpius* shrubs in European black pine stands. Forest Ecology and Management 126:377-383.

Van Wyk, J.A. and Bath, G.F. 2002. The FAMACHA© system for managing *haemonchosis* in sheep and goats by clinically identifying individual animals for treatment. Veterinary Research 33:509-529.

Vatta, A.F., B.A. Letty, M.J. van der Linde, E.F. van Wijk, J.W. Hansen, R.C. Krecek. 2001. Testing for clinical anaemia caused by *H.* spp. in goats farmed under resource-poor conditions in South Africa using an eye colour chart developed for sheep. Vet. Parasitol., 99:1-14.

Vavra, M. 2005. Livestock grazing and wildlife: developing compatibilities. Rangeland Ecology and Management 58:128-134.

Walker, B.H. 1993. Stability in rangelands: ecology and economics. Proc. Int. Grassl. Cong. 17:1885-1890.

Walker, J.,L. Coffey, and T. Faller. 2006. Improving grazing land with multi-species grazing. Targeted Grazing: A natural approach to vegetation management and landscape enhancement, ASI, Cottrell Printing, Centennial, Colorado. pp 50-55.

Wang, L., A. Nguluma, M.L. Leite-Browning, R. Browning. 2017. Differences among four meat goat breeds for doe fitness indicator traits in the southeastern United States. J. Anim. Sci. 95:1481-1488.

Werner, P.A., B.H. Walker, and P.A. Stott. 1990. Introduction: savanna ecology and management: Australian perspectives and intercontinental comparisons. Journal of Biogeography 17:343–344.

Willard, E.E. and C.M. McKell. 1978. Sprouting and carbohydrate reserve of two wildland shrubs following defoliation. Journal of Range Management 31:141-145.

Will-Wolf, S. and F. Stearns. 1999. Dry soil oak savanna in the Great Lakes region. Pages 135-154 in R.C. Anderson, J.S. Fralish, and J.M. Baskin, editors. Savanna, Barrens, and rock outcrop plant communities of North America. Cambridge University Press, Cambridge, United Kingdom.

Williamson, C. 2015. Goats in the forest: a different kind of land management. Natural Resources Foundation of Wisconsin. Land and Waters. < https://www.wisconservation.org/goats-forest-different-kind-land-management/>, accessed 7/1/19.

Wisconsin Department of Natural Resources (WDNR). 2012. Wisconsin's Endangered Resources. Accessed December 4, 2012. <http://dnr.wi.gov/topic/EndangeredResources/>.

Wisconsin Department of Natural Resources. 2015. The ecological landscapes of Wisconsin: An assessment of ecological resources and a guide to planning sustainable management. Chapter 20, Southwest Savanna Ecological Landscape. Wisconsin Department of Natural Resources, PUB-SS1131V 2015, Madison.

Xiong, S., and C. Nilsson. 1999. The effects of plant litter on vegetation: a meta-analysis. Journal of Ecology 87:984-994.

Zedler, P. 2013. Personal communication with Cherrie Nolden on February 19, 2013. Nelson Institute for Environmental Studies, University of Wisconsin-Madison, Madison, Wisconsin.

APPENDIX A:

Tables and Data for Chapter 2

Split Plot Interseeding Study Design Impacts

The original study design included an interseeding, in June 2011, of desirable native forb and graminoid species into a randomly selected half of each treatment in every block of the study site. There was sufficient moisture for germination in spring of 2011, but the remainder of the summer was a drought and the following year's growing season was also a drought (Figure 1). Given the weather, it was likely that the interseeded species did not survive if they germinated. In order to assess the effect of the interseeding split plot treatment, cover for all species that were interseeded were evaluated using linear mixed models (PROC MIXED, SAS Inst. Inc., Cary, NC). Block was considered the experimental unit in each model. Class variables were quadrat, treatment, interseeding and block. Models contained a term for treatment only, and quadrat, interseeding and block were all used as random terms. For all models, least squares means were considered different when protected by a significant *F*-test ($P \leq 0.05$). There were no significant differences, so the split plot was disregarded in analyses of other response variables for this research. Table 1 includes the 2014 percent cover means for each plant in the seeding mix by Interseeding treatment and shows that there were no significant differences in species cover in the Non-Seeded vs. Seeded split plots for any of the interseeded species in

2014. The plantings failed to induce a detectable change in those sections of the treatments, so we felt confident in disregarding the split plot design for the analysis of the data for this research project.

Table 1. Interseeded Species % Cover by Seeding Split Plots in 2014

		Split Plot Treatment1					
Common Name	**Species**	**NonSeeded**		**Seeded**		**SE**	***P-value2***
Big Bluestem	*Andropogon gerardii*	0.000	a	0.111	a	0.707	0.4226
Virginia Wild Rye	*Elymus virginicus*	2.500	a	1.833	a	15.208	0.3716
Bergamot	*Monarda fistulosa*	0.907	a	1.222	a	0.467	0.3031
Yellow Coneflower	*Ratibida pinnata*	0.000	a	0.019	a	0.707	0.4226
Black Eyed Susan	*Rudbeckia hirta*	0.000	a	0.019	a	0.707	0.4226
Stiff Goldenrod	*Solidago rigidum*	0.111	a	0.111	a	1.000	1.0000
Indiangrass	*Sorghastrum nutans*	0.000	a	0.111	a	0.707	0.4226
Sky Blue Aster	*Symphyotrichum oolentangiense*	0.389	a	0.444	a	6.002	0.3906
Culvers Root	*Veronicastrum virginicum*	0.222	a	0.037	a	2.279	0.9993
Golden Alexander	*Zizia aurea*	0.000	a	0.333	a	1.225	0.2253

[1] Mixed model means and SE associated with comparison of split plot main-effects means. Percent cover per 1 square meter from 270 quadrats

[2] Mixed model ranked *P* value associated with treatment *F-test*.

- No values
-

Table 2. Interseeded Species % Cover, by Treatment in 2014

Common Name	Species	Browsing Treatments						SE	*P-value2*
		Control		Light		Heavy			
Big Bluestem	*Andropogon gerardii*	0.000	a	0.167	a	0.000	a	0.866	0.4096
Virginia Wild Rye	*Elymus virginicus*	2.500	a	20.556	a	1.944	a	14.710	0.6589
Bergamot	*Monarda fistulosa*	1.028	a	0.722	a	1.444	a	27.360	0.3616
Yellow Coneflower	*Ratibida pinnata*	0.028	a	0.000	a	0.000	a	0.866	0.4096
Black Eyed Susan	*Rudbeckia hirta*	0.028	a	0.000	a	0.000	a	0.866	0.4096
Stiff Goldenrod	*Solidago rigidum*	0.167	a	0.167	a	0.000	a	1.225	0.6243
Indiangrass	*Sorghastrum nutans*	0.000	a	0.167	a	0.000	a	0.866	0.4096
Sky Blue Aster	*Symphyotrichum oolentangiense*	0.194	a	0.250	a	0.806	a	5.654	0.3682
Culvers Root	*Veronicastrum virginicum*	0.056	a	0.000	a	0.333	a	2.038	0.5147
Golden Alexander	*Zizia aurea*	0.000	a	0.167	a	0.333	a	1.494	0.4071

[1] Mixed model means and SE associated with comparison of browsing treatment main-effects means. Percent cover per 1 square meter from 270 quadrats

[2] Mixed model ranked *P* value associated with treatment *F-test*.

- No values
-

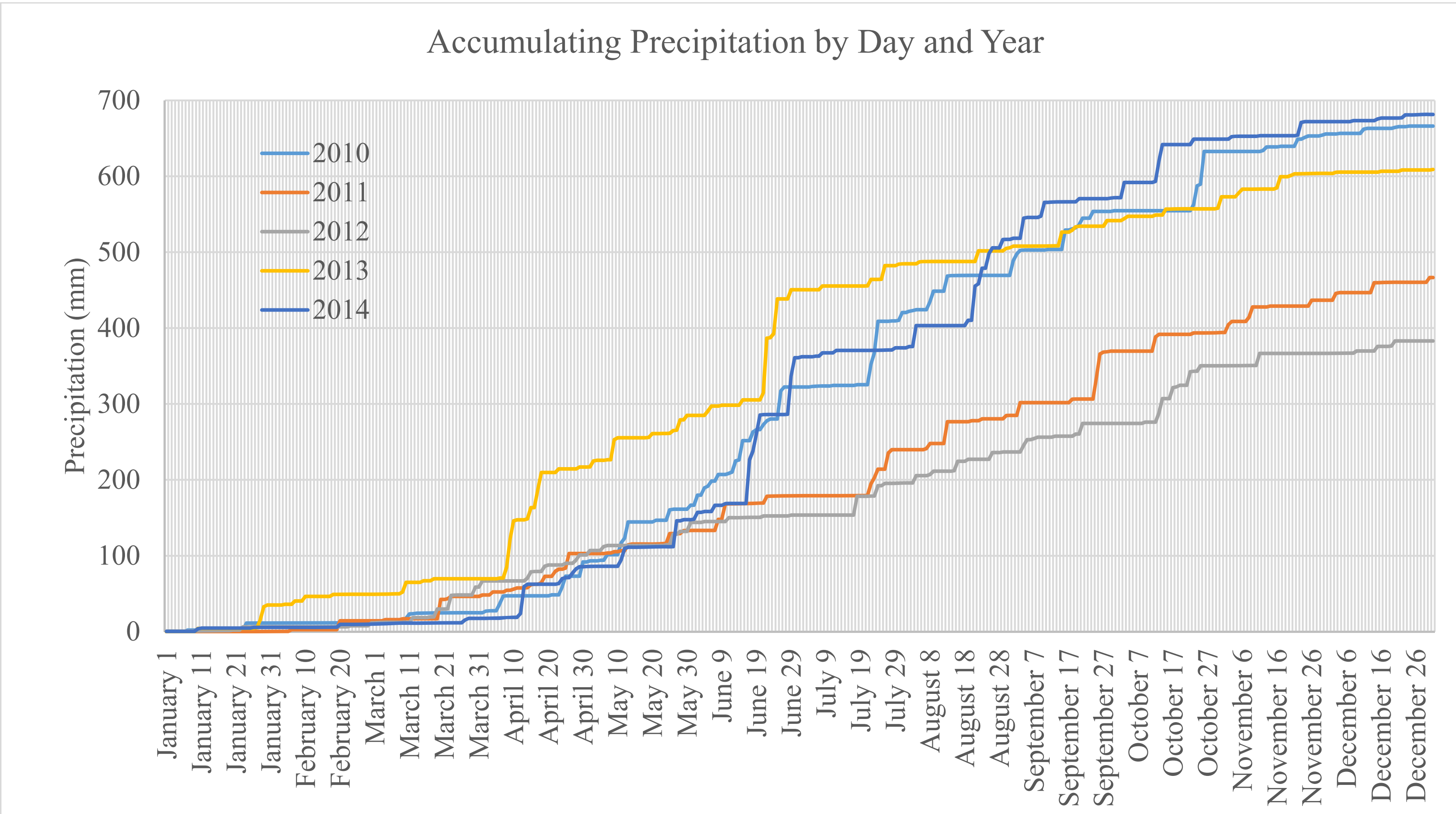


Figure 1. Accumulating Precipitation by Day and Year. The interseeding year, 2011, and the following year, 2012, experienced drought conditions that were not conducive to viable seedling germination and establishment of the native graminoids and forbs chosen to be interseeded into half of each treatment. (Monroe Municipal, 2019)

2014 Woody Species Cover, By Species

Total brush cover showed a significant treatment effect, with Heavily browsed treatments having an average of 44.94% cover and Control treatments having an average of 62.3% cover ($P = 0.0265$).

Table 3. 2014 Woody Species list ordered by mean % cover, with count of quadrats found, and cover by treatment. When brush cover was analyzed by species in 2014, the only species that showed a treatment effect was black raspberry, with 4% cover in Heavily browsed treatments, which was significantly lower than Control and Lightly browsed treatments, 10% cover and 8.4% cover, respectively ($P = 0.0173$). There was a trend ($P = 0.0721$) for grey dogwood in Control treatments to be 2.4 times the cover in Lightly browsed treatments, and Heavily browsed treatments 1.7 times the cover of the Control sites.

				2014 Mean % Cover by treatment [1]							
Common Name	**Scientific Name**	**% Cover** [3]	**Count**	**Control**		**Light**		**Heavy**		**95 % CI**	***P* value**[2]
American Basswood	*Tilia americana*	10.06	85	12.10	a	11.4	a	6.7	a	22.9	0.3366
Slippery Elm	*Ulmus rubra*	8.96	106	8.30	a	10.5	a	8.1	a	17.4	0.3052
Bur Oak	*Quercus macrocarpa*	7.54	55	5.50	a	10.1	a	7.0	a	21.6	0.2480
Black Raspberry	*Rubus occidentalis*	7.44	153	10.00	a	8.4	a	4.0	b	10.1	0.0173
Virginia Creeper	*Parthenocissus quinquefolia*	7.24	138	5.80	a	8.3	a	7.7	a	11.5	0.1170
Grey Dogwood	*Cornus racemosa*	6.34	80	3.80	a	8.9	a	6.3	a	15.4	0.0721

Common Prickly Ash	*Zanthoxylum americanum*	4.63	88	4.1	a	3.5	a	6.3	a	12.0	0.6012
Missouri Gooseberry	*Ribes missouriense*	4.47	91	3.9	a	3.8	a	5.7	a	9.1	0.3569
River Bank Grape	*Vitis riparia Michx*	3.76	91	3.8	a	4.5	a	3.0	a	6.9	0.3260
Wild Black Cherry	*Prunus serotina*	3.73	36	5.6	a	3.2	a	2.4	a	14.2	0.4067
Honeysuckle	*Lonicera spp.*	3.06	51	2.4	a	2.7	a	4.1	a	9.9	0.9972
Poison Ivy	*Toxicodendron radicans*	2.96	32	1.3	a	3.6	a	4.0	a	11.0	0.4512
Red Raspberry	*Rubus idaeus*	2.93	58	3.8	a	2.7	a	2.3	a	7.5	0.5645
Eastern Black Walnut	*Juglans nigra*	2.68	19	3.0	a	2.2	a	2.8	a	13.1	0.6805
American Hazelnut	*Corylus americana*	2.53	33	1.8	a	4.1	a	1.8	a	9.5	0.6926
Quaking Aspen	*Populus tremuloides*	2.34	34	1.9	a	2.3	a	2.8	a	10.0	0.8184
Chokecherry	*Prunus virginiana*	2.33	40	1.9	a	2.7	a	2.3	a	8.1	0.8864
Blackberry	*Rubus allegheniensis*	2.33	62	2.2	a	2.6	a	2.2	a	5.4	0.8733
Shagbark Hickory	*Carya ovata*	1.66	26	2.0	a	1.9	a	1.1	a	7.1	0.9413
Butternut	*Juglans cinerea*	1.31	8	0.0	a	2.0	a	1.9	a	10.0	0.1842
Smooth Sumac	*Rhus glabra*	1.27	32	1.6	a	1.4	a	0.8	a	4.7	0.4726
Nannyberry	*Viburnum lentago*	1.08	15	0.7	a	2.1	a	0.4	a	7.0	0.4256
American Plum	*Prunus americana*	1.03	26	1.1	a	0.4	a	1.6	a	4.2	0.3189
Hawthorn	*Crataegus spp.*	0.94	26	1.4	a	1.0	a	0.4	a	3.7	0.4493
Downy Arrowwood	*Viburnum rafinesqueanum*	0.84	16	0.4	a	1.3	a	0.8	a	3.9	0.5550
Elderberry	*Sambucus canadensis*	0.57	4	1.7	a	0.0	a	0.0	a	5.7	0.4096
Boxelder	*Acer negundo*	0.53	9	1.0	a	0.5	a	0.1	a	5.4	0.8088

Black Oak	*Quercus velutina*	0.48	4	0.0	a	0.0	a	1.4	a	5.3	0.8082
American Elm	*Ulmus americana*	0.42	2	0.0	a	0.0	a	1.3	a	5.4	0.4096
Autumn Olive	*Elaeagnus umbellata*	0.42	10	0.4	a	0.2	a	0.6	a	2.9	0.9186
Multiflora Rose	*Rosa multiflora*	0.33	6	0.5	a	0.2	a	0.3	a	2.5	0.9999
Wild Rose	*Rosa spp.*	0.32	15	0.0	a	0.4	a	0.6	a	1.9	0.1056
Summer Grape	*Vitis aestivalis*	0.13	4	0.1	a	0.3	a	0.0	a	1.7	0.4096
Willow	*Salix spp.*	0.11	2	0.0	a	0.3	a	0.0	a	1.7	0.1946
Apple	*Malus spp.*	0.06	2	0.0	a	0.0	a	0.2	a	0.9	0.1946
Mulberry	*Morus spp.*	0.06	1	0.2	a	0.0	a	0.0	a	0.9	0.4096
Hophornbeam	*Ostrya virginiana*	0.06	1	0.2	a	0.0	a	0.0	a	0.9	0.4096
Northern Red Oak	*Quercus rubra*	0.05	5	0.0	a	0.1	a	0.1	a	0.3	0.8200
Native Honeysuckle	*Lonicera dioica L.*	0.02	2	0.1	a	0.0	a	0.0	a	0.2	0.4096
Staghorn Sumac	*Rhus typhina*	0.01	1	0.0	a	0.0	a	0.0	a	0.2	0.4096
Clematis Vine	*Clematis spp.*	0.01	1	0.0	a	0.0	a	0.0	a	0.2	0.4096
Sugar Maple	*Acer saccharum Marsh.*	0.00	0	--	--	--	--	--	--		--
Hackberry	*Celtis occidentalis*	0.00	0	--	--	--	--	--	--		--
Red Osier Dogwood	*Cornus sericea*	0.00	0	--	--	--	--	--	--		--
Common Buckthorn	*Rhamnus cathartica*	0.00	0	--	--	--	--	--	--		--
Lady Fern	*Athyrium filix-femina*	0.00	0	--	--	--	--	--	--		--
Cranberry Viburnum	*Viburnum trilobum*	0.00	0	--	--	--	--	--	--		--
Ash	*Fraxinus spp*	0.00	0	--	--	--	--	--	--		--

[1] Mixed model means and 95% CI associated with comparison of treatment main-effects means. [2] Mixed model ranked P value associated with treatment *F*-test. 3 Percent cover per 1 square meter averaged from 270 quadrats, 90 per treatment.

Table 4. 2014 Dead stem counts per 5 square meter, by species and treatment. Stem counts were conducted at 9 quadrats per treatment and are reported below as mean stem count by species per 5 square meters. There was a trend for more dead stems of hackberry in Lightly browsed treatments than in Control treatments, and Heavily browsed had intermediate levels of dead hackberry stems (*P*= 0.1089).

		Treatment1							
Common Name	**Species**	**Control**		**Light**		**Heavy**		**SE**	***P* value2**
Boxelder	*Acer negundo*	3.17	a	2.72	a	2.89	a	1.545	0.7552
Sugar Maple	*Acer saccharum Marsh.*	0.06	a	0.00	a	0.00	a	0.032	0.4096
Lady Fern	*Athyrium filix-femina*	1.72	a	1.67	a	1.44	a	0.901	0.9692
Shagbark Hickory	*Carya ovata*	0.00	--	0.00	--	0.00	--	--	--
Hackberry	*Celtis occidentalis*	2.83	a	9.39	a	7.89	a	3.770	0.1089
Grey Dogwood	*Cornus racemosa*	10.50	a	7.33	a	11.67	a	3.248	0.5688
Red Osier Dogwood	*Cornus sericea*	9.56	a	9.28	a	9.06	a	4.396	0.7532
American Hazelnut	*Corylus americana*	0.00	--	0.00	--	0.00	--	--	--
Hawthorn	*Crataegus spp.*	0.00	--	0.00	--	0.00	--	--	--

Autumn Olive	*Elaeagnus umbellata*	0.06	a	0.11	a	0.11	a	0.077	0.8172
Ash	*Fraxinus spp*	0.00	--	0.00	--	0.00	--	--	--
Butternut	*Juglans cinerea*	0.06	a	0.00	a	0.00	a	0.032	0.4096
Eastern Black Walnut	*Juglans nigra*	0.00	--	0.00	--	0.00	--	--	--
Honeysuckle	*Lonicera spp.*	0.00	a	0.06	a	1.39	a	0.813	0.6154
Apple	*Malus spp.*	1.67	a	0.50	a	2.00	a	1.119	0.7418
Mulberry	*Morus spp.*	3.22	a	2.50	a	2.89	a	1.573	0.8794
Quaking Aspen	*Populus tremuloides*	2.83	a	0.61	a	5.61	a	3.139	0.2582
American Plum	*Prunus americana*	0.00	--	0.00	--	0.00	--	--	--
Wild Black Cherry	*Prunus serotina*	3.44	a	2.89	a	5.89	a	2.159	0.5039
Chokecherry	*Prunus virginiana*	0.00	a	0.06	a	0.00	a	0.032	0.4096
Bur Oak	*Quercus macrocarpa*	0.00	a	0.06	a	0.06	a	0.045	0.6243
Northern Red Oak	*Quercus rubra*	0.00	a	0.78	a	0.50	a	0.341	0.3086
Black Oak	*Quercus velutina*	0.00	a	0.61	a	0.00	a	0.353	0.4096
Common Buckthorn	*Rhamnus cathartica*	0.33	a	1.67	a	0.39	a	0.655	0.3298
Smooth Sumac	*Rhus glabra*	4.00	a	3.72	a	7.06	a	1.842	0.3740
Staghorn Sumac	*Rhus typhina*	6.83	a	6.00	a	7.72	a	1.755	0.6440
Missouri Gooseberry	*Ribes missouriense*	8.33	a	10.78	a	3.89	a	3.334	0.2847
Multiflora Rose	*Rosa multiflora*	1.78	a	2.28	a	0.67	a	0.959	0.3177

Wild Rose	*Rosa spp.*	2.28	a	2.50	a	1.56	a	0.854	0.7080
Blackberry	*Rubus allegheniensis*	3.00	a	1.78	a	5.67	a	1.987	0.6460
Red Raspberry	*Rubus idaeus*	1.00	a	0.50	a	0.17	a	0.450	0.9442
Black Raspberry	*Rubus occidentalis*	0.00	a	0.00	a	0.33	a	0.193	0.4096
Willow	*Salix spp.*	3.83	a	3.61	a	2.83	a	1.314	0.8040
Elderberry	*Sambucus canadensis*	3.72	a	1.67	a	3.83	a	2.538	0.9732
American Basswood	*Tilia americana*	0.06	a	0.67	a	0.00	a	0.386	0.4096
American Elm	*Ulmus americana*	0.00	a	3.56	a	1.72	a	2.195	0.5157
Slippery Elm	*Ulmus rubra*	4.83	a	3.10	a	2.50	a	2.290	0.8752
Nannyberry	*Viburnum lentago*	1.06	a	6.11	a	1.67	a	1.704	0.3700
Downy Arrowwood	*Viburnum rafinesqueanum*	1.39	a	2.89	a	0.44	a	1.779	0.4116
Cranberry Viburnum	*Viburnum trilobum*	0.44	a	3.89	a	5.00	a	2.682	0.2937
Common Prickly Ash	*Zanthoxylum americanum*	8.72	a	7.33	a	4.22	a	1.476	0.2596

[1] Mixed model means and 95% CI associated with comparison of treatment main-effects means.

[2] Mixed model ranked *P* value associated with treatment *F-test*.

- No values
-

Table 5. 2014 Living stem counts per 5 square meter, by species and treatment. Stem counts were conducted at 9 quadrats per treatment and are reported below as mean stem count by species per 5 square meters. There were two woody species that showed treatment effects for living stem counts. There were more alive stems of mulberry in Control browsed treatments than in Lightly browsed treatments, and Heavily browsed had intermediate levels of dead hackberry stems (*P*= 0.0202). There were more alive stems of hackberry in Lightly browsed treatments than in Control treatments, and Heavily browsed had intermediate levels of dead hackberry stems (*P*= 0.0332).

		Treatment1							
Common Name	**Species**	**Control**		**Light**		**Heavy**		**SE**	***P* value2**
Willow	*Salix spp.*	3.89	a	3.89	a	4.28	a	0.993	0.8957
Wild Rose	*Rosa spp.*	0.00	--	0.00	--	0.00	--	--	--
American Plum	*Prunus americana*	2.83	a	0.00	a	0.00	a	1.636	0.4096
Wild Black Cherry	*Prunus serotina*	0.72	a	2.72	a	1.78	a	1.123	0.4693
Eastern Black Walnut	*Juglans nigra*	0.00	--	0.00	--	0.00	--	--	--
American Basswood	*Tilia americana*	2.11	a	3.28	a	3.06	a	2.160	0.8627
Staghorn Sumac	*Rhus typhina*	3.83	a	5.33	a	3.11	a	1.005	0.1704
Smooth Sumac	*Rhus glabra*	4.33	a	2.83	a	1.78	a	0.996	0.3322
Slippery Elm	*Ulmus rubra*	6.00	a	13.72	a	4.56	a	2.851	0.1654
Red Raspberry	*Rubus idaeus*	0.17	a	2.94	a	1.72	a	1.356	0.4288
Red Osier Dogwood	*Cornus sericea*	1.72	a	1.56	a	0.67	a	0.711	0.2131
Northern Red Oak	*Quercus rubra*	0.61	a	0.00	a	0.00	a	0.353	0.4096
Common Prickly Ash	*Zanthoxylum americanum*	2.17	a	2.72	a	2.78	a	1.152	0.4323

Nannyberry	*Viburnum lentago*	1.83	a	3.56	a	2.56	a	1.541	0.7918
Multiflora Rose	*Rosa multiflora*	4.83	a	3.06	a	6.67	a	3.28	0.7821
Mulberry	***Morus spp.***	**11.22**	**a**	**9.39**	**b**	**3.78**	**ab**	**1.716**	**0.0202**
Sugar Maple	*Acer saccharum Marsh.*	0.33	a	0.00	a	0.00	a	0.193	0.4096
Honeysuckle	*Lonicera spp.*	0.00	--	0.00	--	0.00	--	--	--
Shagbark Hickory	*Carya ovata*	0.11	a	0.00	a	0.33	a	0.203	0.5744
American Hazelnut	*Corylus americana*	0.00	--	0.00	--	0.00	--	--	--
Hawthorn	*Crataegus spp.*	0.00	a	0.44	a	2.17	a	1.27	0.2749
Hackberry	***Celtis occidentalis***	**4.72**	**b**	**10.50**	**a**	**7.67**	**ab**	**2.354**	**0.0332**
Grey Dogwood	*Cornus racemosa*	0.00	--	0.00	--	0.00	--	--	--
Missouri Gooseberry	*Ribes missouriense*	14.61	a	13.56	a	4.33	a	6.391	0.3629
Lady Fern	*Athyrium filix-femina*	0.44	a	0.39	a	1.67	a	0.624	0.3245
Elderberry	*Sambucus canadensis*	0.00	a	0.00	a	0.56	a	0.032	0.4096
Cranberry Viburnum	*Viburnum trilobum*	0.00	--	0.00	--	0.00	--	--	--
Chokecherry	*Prunus virginiana*	1.50	a	0.56	a	0.83	a	0.699	0.7081
Butternut	*Juglans cinerea*	0.00	--	0.00	--	0.00	--	--	--
Bur Oak	*Quercus macrocarpa*	0.00	a	0.00	a	2.50	a	1.443	0.4096
Common Buckthorn	*Rhamnus cathartica*	0.06	a	0.00	a	1.39	a	0.803	0.6243
Boxelder	*Acer negundo*	6.33	a	3.22	a	2.39	a	2.553	0.3439
Blackberry	*Rubus allegheniensis*	4.67	a	8.50	a	4.78	a	2.164	0.3628
Black Raspberry	*Rubus occidentalis*	2.44	a	2.06	a	1.83	a	1.409	0.3602
Black Oak	*Quercus velutina*	0.33	a	0.00	a	0.00	a	0.193	0.4096

Autumn Olive	*Elaeagnus umbellata*	2.72	a	9.39	a	10.11	a	3.89	0.3856
Quaking Aspen	*Populus tremuloides*	2.33	a	2.11	a	0.67	a	1.386	0.7265
Ash	*Fraxinus spp*	0.06	a	0.00	a	0.00	a	0.032	0.4096
Downy Arrowwood	*Viburnum rafinesqueanum*	0.00	--	0.00	--	0.00	--	--	--
Apple	*Malus spp.*	0.39	a	1.00	a	1.28	a	0.757	0.9188
American Elm	*Ulmus americana*	3.22	a	3.78	a	0.00	a	2.51	0.1981

[1] Mixed model means and 95% CI associated with comparison of treatment main-effects means.

[2] Mixed model ranked *P* value associated with treatment *F-test*.

-- No values

Aggressive Species

The following aggressive species were found at the research site, and the data below summarize the Treatment differences in the number of quadrats containing each species (richness), and the average percent cover (per square meter).

Table 6. 2014 Invasive species mean % cover by treatment. ANOVA results of mean % cover, per square meter, by treatment of each invasive species. *P* values are ranked for normality, while means and MSEs are reported as unranked values. Although there was a significant increase in invasive forb cover, from 14.2% in control sites to 27.5% in Heavily browsed sites ($P = 0.0313$), individual species cover in the invasive category for all plant lifeforms at the research site showed no significant ($P < 0.05$) increases in cover between treatments in 2014. The same was true for individual species richness of the invasive species. There was a trend ($P < 1.0$) for both a greater cover and richness in Heavily browsed sites vs. Control sites for the following species: burdock ($P = 0.070$, $P = 0.0557$), common mullein ($P = 0.055$, $P = 0.0542$), and bull thistle ($P = 0.060$, $P = 0.0604$), cover and richness respectively.

			% Cover1				
Common Name	**Species Name**	**Group**	**Control**	**Light**	**Heavy**	**SE**	***P* value2**
Garlic Mustard	*Alliaria petiolata*	Forb	0.58	0.39	1.42	0.52	0.3620
Burdock	*Arctium minus*	Forb	1.56	5.42	7.28	2.23	0.0698
Plumeless Thistle	*Carduus acanthoides*	Forb	0.00	0.03	0.17	0.10	0.6243
Nodding/Musk Thistle	*Carduus nutans*	Forb	0.17	0.00	0.00	0.10	0.4096
Canada Thistle	*Cirsium arvense*	Forb	1.94	1.61	2.81	0.79	0.2531
Bull Thistle	*Cirsium vulgare*	Forb	0.06	1.81	1.28	0.46	0.0595
Wild Yam	*Dioscorea villosa*	Forb	0.00	0.17	0.22	0.17	0.4096
Motherwort	*Leonurus cardiaca*	Forb	0.28	0.94	1.39	0.68	0.3761
White Sweet clover	*Melilotus alba*	Forb	--	--	--	--	--

Yellow Sweet Clover	*Melilotus officinalis*	Forb	0.72	1.17	1.11	0.63	0.4838
Wild Parsnip	*Pastinaca sativa*	Forb	0.64	1.86	0.39	0.62	0.4307
Crown Vetch	*Securigera varia*	Forb	0.00	0.00	0.94	0.55	0.4096
Canada Goldenrod	*Solidago canadensis*	Forb	6.47	6.03	6.28	1.11	0.9302
Japanese Hedge Parsley	*Torilis japonica*	Forb	0.17	0.00	0.00	0.10	0.4096
Red Clover	*Trifolium pratense*	Forb	0.22	0.47	1.08	0.61	0.4795
Common Mullein	*Verbascum thapsus*	Forb	0.03	0.36	0.67	0.22	0.0549
Quackgrass	*Elytrigia repens*	Graminoid	0.19	0.19	0.17	0.23	0.8147
Reed Canarygrass	*Phalaris arundinacea*	Graminoid	0.50	1.39	0.36	0.63	0.3313
Autumn Olive	*Elaeagnus umbellata*	Woody	0.39	0.22	0.64	0.34	0.9186
Honeysuckle	*Lonicera spp.*	Woody	2.42	2.67	4.11	1.33	0.9972
Common Buckthorn	*Rhamnus cathartica*	Woody	--	--	--	--	--
Multiflora Rose	*Rosa multiflora*	Woody	0.47	0.19	0.33	0.26	0.9999

[1] Mixed model means and SE associated with comparison of treatment main-effects means.

[2] Mixed model ranked *P* value associated with treatment *F-test*.

-- No values

Table 7. 2914 Invasive species count by treatment

Common Name	Species Name	Group	Count1		
			Control	Light	Heavy
Garlic Mustard	*Alliaria petiolata*	Forb	6	4	11
Burdock	*Arctium minus*	Forb	11	23	29
Plumeless Thistle	*Carduus acanthoides*	Forb	0	1	1
Nodding/Musk Thistle	*Carduus nutans*	Forb	1	0	0
Canada Thistle	*Cirsium arvense*	Forb	16	18	31
Bull Thistle	*Cirsium vulgare*	Forb	2	15	16
Wild Yam	*Dioscorea villosa*	Forb	0	1	3
Motherwort	*Leonurus cardiaca*	Forb	5	9	15
White Sweet clover	*Melilotus alba*	Forb	--	--	--
Yellow Sweet Clover	*Melilotus officinalis*	Forb	6	12	6
Wild Parsnip	*Pastinaca sativa*	Forb	8	9	4
Crown Vetch	*Securigera varia*	Forb	0	0	1
Canada Goldenrod	*Solidago canadensis*	Forb	53	54	51
Japanese Hedge Parsley	*Torilis japonica*	Forb	1	0	0
Red Clover	*Trifolium pratense*	Forb	3	7	5
Common Mullein	*Verbascum thapsus*	Forb	1	3	9
Quackgrass	*Elytrigia repens*	Graminoid	2	2	1
Reed Canarygrass	*Phalaris arundinacea*	Graminoid	3	7	3
Autumn Olive	*Elaeagnus umbellata*	Woody	4	3	3
Honeysuckle	*Lonicera spp.*	Woody	17	17	17
Common Buckthorn	*Rhamnus cathartica*	Woody	--	--	--
Multiflora Rose	*Rosa multiflora*	Woody	2	2	2

[1] Count of quadrats where documented; 270 quadrats with 90 per treatment

-- No values

Table 8. 2014 Species list, form, count, and analysis category.

Common Name	Scientific Name	Form	Quadrat Count	Analysis Category						
				Shade	Part Sun	Sun	Savanna Indicator	Invasive	Clonal	Erect
Yarrow	*Achillea millefolium*	Forb	8	0	0	0	0	0	0	X
Garlic Mustard	*Alliaria petiolata*	Forb	21	0	0	0	0	X	0	X
Wild Onion	*Allium canadense*	Forb	2	0	X	X	0	0	0	X
Water Hemp	*Amaranthus rudis*	Forb	1	0	0	0	0	0	0	X
Ragweed, Common	*Ambrosia artemisiifolia*	Forb	5	0	0	0	0	0	0	X
Ragweed, Giant	*Ambrosia trifida*	Forb	13	0	0	0	0	0	0	X
Hog Peanut	*Amphicarpaea bracteata*	Forb	9	X	X	X	0	0	0	0
Tall thimbleweed	*Anemone virginiana*	Forb	2	X	X	0	X	0	0	X
Field Pussytoes	*Antennaria neglecta*	Forb	2	0	X	X	0	0	0	0
Indian Hemp	*Apocynum cannabinum*	Forb	8	0	X	X	0	0	0	X
Columbine	*Aquilegia canadensis*	Forb	8	X	X	0	0	0	0	X
Burdock	*Arctium minus*	Forb	63	0	0	0	0	X	0	X
Jack in the Pulpit	*Arisaema triphyllum*	Forb	5	X	0	0	0	0	0	0
Common Milkweed	*Asclepias syriaca*	Forb	5	0	0	X	0	0	0	X
Sky Blue Aster	*Symphyotrichum oolentangiense*	Forb	20	0	X	0	0	0	0	X
Yellow Rocket	*Barbarea vulgaris*	Forb	25	0	0	0	0	0	0	X
Shepherd's Purse	*Capsella bursa-pastoris*	Forb	1	0	0	0	0	0	0	X

Plumeless Thistle	*Carduus acanthoides*	Forb	2	0	0	0	0	X	0	X
Nodding/Musk Thistle	*Carduus nutans*	Forb	1	0	0	0	0	X	0	X
Lambsquarters	*Chenopodium album*	Forb	4	0	0	0	0	0	0	X
Enchanter's Nightshade	*Circaea lutetiana*	Forb	65	X	X	0	0	0	0	X
Canada Thistle	*Cirsium arvense*	Forb	65	0	0	0	0	X	0	X
Field/Prairie Thistle	*Cirsium discolor*	Forb	31	0	X	0	0	0	0	X
Bull Thistle	*Cirsium vulgare*	Forb	33	0	0	0	0	X	0	X
Field Bindweed	*Convulvulus arvensis*	Forb	1	0	0	0	0	0	0	0
Honewort	*Cryptotaenia canadensis*	Forb	20	0	0	0	0	0	0	X
Wild Carrot	*Daucus carota*	Forb	9	0	0	0	0	0	0	X
Naked Flower Tick Trefoil	*Desmodium nudiflorum*	Forb	18	X	X	0	0	0	0	0
Deptford Pink	*Dianthus armeria*	Forb	3	0	0	0	0	0	0	X
Wild Yam	*Dioscorea villosa*	Forb	4	0	0	0	0	X	0	0
Robin's Plantain	*Erigeron pulchellus*	Forb	18	0	X	X	X	0	0	0
Fleabane Daisy	*Erigeron strigosus*	Forb	47	0	X	X	0	0	0	X
Long/Lance Leaf Goldenrod	*Euthamia graminifolia*	Forb	7	0	X	X	0	0	0	X
Wild Strawberry	*Fragaria virginiana*	Forb	132	X	X	X	0	0	0	0
Bedstraw	*Galium spp.*	Forb	149	X	X	0	0	0	0	0
Wild Geranium	*Geranium maculatum*	Forb	111	X	X	0	0	0	0	0
White Avens	*Geum canadense*	Forb	79	X	X	X	0	0	0	X
Creeping Charlie	*Glechoma hederacea*	Forb	2	0	0	0	0	0	0	0

American Cow Parsnip	*Heracleum sphondylium ssp montanum*	Forb	1	0	0	0	0	0	0	X
Virginia Waterleaf	*Hydrophyllum virginianum*	Forb	4	0	0	0	0	0	0	X
St John's Wort	*Hypericum pyramidatum*	Forb	12	0	0	0	0	0	0	X
Orange Jewelweed	*Impatiens capensis*	Forb	5	0	0	0	0	0	0	X
Wild Lettuce	*Lactuca virosa*	Forb	21	0	0	0	0	0	0	X
Wood Nettle	*Laportea canadensis*	Forb	6	0	0	0	0	0	0	X
Pea Vine Lathyrus	*Lathyrus latifolius*	Forb	4	0	0	0	0	0	0	0
Motherwort	*Leonurus cardiaca*	Forb	29	0	0	0	0	X	0	X
Michigan Lily	*Lilium michiganense*	Forb	1	0	X	X	0	0	0	X
Fringed Loosestrife	*Lysimachia ciliata*	Forb	5	X	X	0	0	0	0	X
False Lily-of-the-valley	*Maianthemum canadense*	Forb	2	0	0	0	0	0	0	0
False Solomon's Seal	*Maianthemum racemosum*	Forb	24	0	0	0	0	0	0	X
Starry Solomon's Seal	*Maianthemum stellatum*	Forb	3	0	0	0	0	0	0	X
Ostrich Fern	*Matteuccia struthiopteris*	Forb	4	0	0	0	0	0	0	X
Black Medic	*Medicago lupulina*	Forb	64	0	0	0	0	0	0	0
Yellow Sweet Clover	*Melilotus officinalis*	Forb	24	0	0	0	0	X	0	X
White Sweet clover	*Melilotus alba*	Forb	0	0	0	0	0	X	0	X
Bergamot	*Monarda fistulosa*	Forb	25	0	X	X	0	0	0	X
Stiff Goldenrod	*Solidago rigidum*	Forb	2	0	0	0	0	0	0	X

Yellow Wood Sorrel	*Oxalis stricta*	Forb	18	0	0	0	0	0	0	0
Longstyle Sweet Cicily	*Ozmorhiza longistylis*	Forb	21	X	X	0	0	0	0	X
Wild Parsnip	*Pastinaca sativa*	Forb	21	0	0	0	0	X	0	X
Pale Smartweed	*Persicaria lapathifolia*	Forb	3	0	0	0	0	0	0	X
Smooth Ground Cherry	*Physalis subglabrata*	Forb	11	0	X	X	0	0	0	X
Virginia Ground Cherry	*Physalis virginiana*	Forb	11	0	0	0	0	0	0	X
Black-Seeded Plantain	*Plantago rugelii*	Forb	20	0	0	0	0	0	0	0
Mayapple	*Podophyllum peltatum*	Forb	4	X	X	0	0	0	0	X
Smooth Solomon Seal	*Polygonatum biflorum*	Forb	23	X	X	X	0	0	0	X
Rough Cinquefoil	*Potentilla norvegica (running)*	Forb	5	0	0	0	0	0	0	0
Tall Cinquefoil	*Potentilla arguta*	Forb	18	0	0	X	0	0	0	X
Sulfur Cinquefoil	*Potentilla recta*	Forb	26	0	0	0	0	0	0	X
Old Field Cinquefoil	*Potentilla simplex*	Forb	10	0	X	X	0	0	0	0
Little leaf buttercup	*Ranunculus arborvitus*	Forb	1	X	X	0	0	0	0	0
Early Buttercup	*Ranunculus fasicularis*	Forb	19	0	X	X	X	0	0	0
Prairie Buttercup	*Ranunculus rhomboideus*	Forb	9	0	0	X	X	0	0	0
Yellow Coneflower	*Ratibida pinnata*	Forb	1	0	X	X	0	0	0	X

Black Eyed Susan	*Rudbeckia hirta*	Forb	1	0	X	X	0	0	0	X
Curly Dock	*Rumex crispus*	Forb	4	0	0	0	0	0	0	X
Clustered Black Snakeroot	*Sanicula marilandica*	Forb	56	X	X	0	0	0	0	X
Figwort	*Scrophularia marilandica*	Forb	1	X	X	0	0	0	0	X
Crown Vetch	*Securigera varia*	Forb	1	0	0	0	0	X	0	X
Bladder Campion	*Silene latifolia*	Forb	27	0	0	0	0	0	0	X
Upright Carrionflower	*Smilax ecirrhata*	Forb	2	X	X	0	0	0	0	0
Hairy Carrionflower	*Smilax mollis*	Forb	17	0	0	0	0	0	0	0
Eastern Black Nightshade	*Solanum ptycanthum*	Forb	8	0	0	0	0	0	0	X
Tall Goldenrod	*Solidago altissima*	Forb	17	0	0	0	0	0	0	X
Canada Goldenrod	*Solidago canadensis*	Forb	158	0	X	X	0	X	0	X
Chickweed	*Stellaria media*	Forb	45	0	0	0	0	0	0	0
Calico Aster	*Symphyotrichum lateriflorum*	Forb	2	0	0	0	0	0	0	X
Purple Stemmed Aster	*Symphyotrichum puniceum*	Forb	10	0	0	0	0	0	0	X
White Arrow-leaf Aster	*Symphyotrichum urophyllum*	Forb	8	0	0	0	0	0	0	X
Dandelion	*Taraxacum officinale*	Forb	237	0	0	0	0	0	0	0
Japanese Hedge Parsley	*Torilis japonica*	Forb	1	0	0	0	0	X	0	X
Spiderwort	*Tradescantia ohiensis*	Forb	3	0	X	X	0	0	0	X
Goats Beard	*Tragopogon dubius*	Forb	1	0	0	0	0	0	0	X

Red Clover	*Trifolium pratense*	Forb	15	0	0	0	0	X	0	0
White Clover	*Trifolium repens*	Forb	7	0	0	0	0	0	0	0
Late Horse Gentian	*Triosteum perfoliatum*	Forb	8	0	X	0	X	0	0	X
Stinging Nettle	*Urtica dioica*	Forb	24	0	0	0	0	0	0	X
Common Mullein	*Verbascum thapsus*	Forb	13	0	0	0	0	X	0	X
Culver's Root	*Veronicastrum virginicum*	Forb	4	0	X	X	X	0	0	X
American Vetch	*Vicia americana*	Forb	12	0	X	X	0	0	0	X
Woodland Violet	*Viola papilionacea*	Forb	81	0	0	0	0	0	0	0
Wood Anemone	*Anemone quinquefolia*	Forb	6	0	0	0	0	0	0	X
Bird's Foot Violet	*Viola pedata*	Forb	12	0	X	X	0	0	0	0
Golden Alexander	*Zizia aurea*	Forb	3	X	X	X	X	0	0	X
Big Bluestem	*Andropogon gerardii*	Graminoid	1	0	0	X	0	0	0	-
Fringed Brome	*Bromus ciliatus*	Graminoid	11	X	X	0	0	0	0	-
Smooth Brome	*Bromus inermis*	Graminoid	6	0	0	0	0	0	0	-
Pennsylvania Sedge	*Carex pensylvanica*	Graminoid	48	X	X	X	0	0	X	-
Orchardgrass	*Dactylis glomerata*	Graminoid	4	0	0	0	0	0	0	-
Virginia Wild Rye	*Elymus virginicus*	Graminoid	86	X	X	X	X	0	0	-
Quackgrass	*Elytrigia repens*	Graminoid	5	0	0	0	0	X	X	-
Tall Fescue	*Festuca arundinacea*	Graminoid	7	0	0	0	0	0	0	-
Panicum	*Panicum spp*	Graminoid	1	0	X	0	0	0	0	-
Reed Canarygrass	*Phalaris arundinacea*	Graminoid	13	0	0	0	0	X	X	-

Timothy	*Phleum pratense*	Graminoid	5	0	0	0	0	0	0	-
Kentucky Bluegrass	*Poa pratensis*	Graminoid	91	0	0	0	0	0	X	-
Indiangrass	*Sorghastrum nutans*	Graminoid	1	0	0	0	0	0	0	-
Boxelder	*Acer negundo*	Woody	9	0	0	0	0	0	0	-
Sugar Maple	*Acer saccharum Marsh.*	Woody	0	0	0	0	0	0	0	-
Lady Fern	*Athyrium filix-femina*	Woody	0	0	0	0	0	0	0	-
Shagbark Hickory	*Carya ovata*	Woody	26	0	0	0	0	0	0	-
Hackberry	*Celtis occidentalis*	Woody	0	0	0	0	0	0	0	-
Clematis Vine	*Clematis spp.*	Woody	1	X	X	X	0	0	0	-
Grey Dogwood	*Cornus racemosa*	Woody	80	0	X	X	0	0	X	-
Red Osier Dogwood	*Cornus sericea*	Woody	0	0	X	X	0	X	X	-
American Hazelnut	*Corylus americana*	Woody	33	X	X	0	0	0	0	-
Hawthorn	*Crataegus spp.*	Woody	26	0	X	0	0	0	0	-
Autumn Olive	*Elaeagnus umbellata*	Woody	10	0	0	0	0	X	0	-
Ash	*Fraxinus spp*	Woody	0	0	0	0	0	0	0	-
Butternut	*Juglans cinerea*	Woody	8	0	0	0	0	0	0	-
Eastern Black Walnut	*Juglans nigra*	Woody	19	0	0	0	0	0	0	-
Native Honeysuckle	*Lonicera dioica L.*	Woody	2	X	X	0	0	0	0	-
Honeysuckle	*Lonicera spp.*	Woody	51	0	0	0	0	X	0	-
Apple	*Malus spp.*	Woody	2	0	0	0	0	0	0	-
Mulberry	*Morus spp.*	Woody	1	0	0	0	0	0	0	-
Hophornbeam	*Ostrya virginiana*	Woody	1	0	0	0	0	0	0	-

Virginia Creeper	*Parthenocissus quinquefolia*	Woody	138	X	X	0	0	0	0	-
Quaking Aspen	*Populus tremuloides*	Woody	34	0	0	0	0	0	0	-
American Plum	*Prunus americana*	Woody	26	X	X	X	0	0	0	-
Wild Black Cherry	*Prunus serotina*	Woody	36	0	0	0	0	0	0	-
Chokecherry	*Prunus virginiana*	Woody	40	0	0	0	0	0	0	-
Bur Oak	*Quercus macrocarpa*	Woody	55	0	0	0	0	0	0	-
Northern Red Oak	*Quercus rubra*	Woody	5	0	0	0	0	0	0	-
Black Oak	*Quercus velutina*	Woody	4	0	0	0	0	0	0	-
Common Buckthorn	*Rhamnus cathartica*	Woody	0	0	0	0	0	X	0	-
Smooth Sumac	*Rhus glabra*	Woody	32	0	X	X	0	0	X	-
Staghorn Sumac	*Rhus typhina*	Woody	1	0	X	X	0	0	X	-
Missouri Gooseberry	*Ribes missouriense*	Woody	91	X	X	0	0	0	0	-
Multiflora Rose	*Rosa multiflora*	Woody	6	0	0	0	0	X	0	-
Wild Rose	*Rosa spp.*	Woody	15	0	X	X	0	0	X	-
Blackberry	*Rubus allegheniensis*	Woody	62	X	X	0	0	0	X	-
Red Raspberry	*Rubus idaeus*	Woody	58	X	X	0	0	0	X	-
Black Raspberry	*Rubus occidentalis*	Woody	153	X	X	0	0	0	X	-
Willow	*Salix spp.*	Woody	2	0	0	X	0	0	X	-
Elderberry	*Sambucus canadensis*	Woody	4	0	X	X	0	0	0	-
American Basswood	*Tilia americana*	Woody	85	0	0	0	0	0	0	-
Poison Ivy	*Toxicodendron radicans*	Woody	32	0	0	0	0	0	0	-
American Elm	*Ulmus americana*	Woody	2	0	0	0	0	0	0	-

Slippery Elm	*Ulmus rubra*	Woody	106	0	0	0	0	0	0	-
Nannyberry	*Viburnum lentago*	Woody	15	X	X	0	0	0	0	-
Downy Arrowwood	*Viburnum rafinesqueanum*	Woody	16	X	X	0	0	0	0	-
Cranberry Viburnum	*Viburnum trilobum*	Woody	0	X	X	0	0	0	0	-
Summer Grape	*Vitis aestivalis*	Woody	4	X	X	X	0	0	0	-
River Bank Grape	*Vitis riparia Michx*	Woody	91	X	X	X	0	0	0	-
Common Prickly Ash	*Zanthoxylum americanum*	Woody	88	X	X	0	0	0	X	-

Table 9. 2014 Forb Species list ordered by mean % cover, with count of quadrats found, and cover by treatment

Common Name	Scientific Name	% Cover[3]	Count	2014 Mean % Cover by treatment[1] Control		Light		Heavy		SEM	*P* value2
Dandelion	*Taraxacum officinale*	11.69	237	11.8	a	10.8	a	12.5	a	1.3	0.8045
Wild Strawberry	*Fragaria virginiana*	9.57	132	8.3	a	8.7	a	11.8	a	2.7	0.1745
Canada Goldenrod	*Solidago canadensis*	6.26	158	6.5	a	6.0	a	6.3	a	1.1	0.9302
Burdock	*Arctium minus*	4.75	63	1.6	a	5.4	a	7.3	a	2.2	0.0698
Clustered Black Snakeroot	*Sanicula marilandica*	4.31	56	0.6	a	4.8	a	2.3	a	2.9	0.3555
Wild Geranium	*Geranium maculatum*	4.04	111	5.1	a	4.0	a	3.0	a	1.1	0.3743
Bedstraw	*Galium* spp.	2.34	149	1.6	a	2.7	a	2.8	a	0.6	0.2314
Canada Thistle	*Cirsium arvense*	2.12	65	1.9	a	1.6	a	2.8	a	0.8	0.2531

White Avens	*Geum canadense*	1.98	79	1.8	a	1.9	a	2.2	a	0.6	0.9450
Woodland Violet	*Viola papilionacea*	1.76	81	1.5	a	1.9	a	1.8	a	0.8	0.9208
Black Medic	*Medicago lupulina*	1.70	64	1.8	a	0.8	a	2.6	a	0.6	0.1719
Fleabane Daisy	*Erigeron strigosus*	1.31	47	0.2	b	2.2	a	1.5	ab	0.5	0.0256
Chickweed	*Stellaria media*	1.25	45	1.1	a	1.3	a	1.3	a	0.6	0.7907
Bergamot	*Monarda fistulosa*	1.06	25	1.0	a	0.7	a	1.4	a	0.5	0.3616
Bull Thistle	*Cirsium vulgare*	1.05	33	0.1	a	1.8	a	1.3	a	0.5	0.0595
Stinging Nettle	*Urtica dioica*	1.04	24	0.8	a	1.3	a	0.9	a	0.8	0.6827
Yellow Sweet Clover	*Melilotus officinalis*	1.00	24	0.7	a	1.2	a	1.1	a	0.6	0.4838
Wild Parsnip	*Pastinaca sativa*	0.96	21	0.6	a	1.9	a	0.4	a	0.6	0.4307
Motherwort	*Leonurus cardiaca*	0.87	29	0.3	a	0.9	a	1.4	a	0.7	0.3761
Garlic Mustard	*Alliaria petiolata*	0.80	21	0.6	a	0.4	a	1.4	a	0.5	0.3620
Enchanter's Nightshade	*Circaea lutetiana*	0.79	65	1.0	a	0.7	a	0.7	a	0.3	0.8416
Naked Flower Tick Trefoil	*Desmodium nudiflorum*	0.77	18	1.0	a	0.5	a	0.8	a	0.4	0.6673
False Solomon's Seal	*Maianthemum racemosum*	0.73	24	0.8	a	0.9	a	0.5	a	0.3	0.8469
Smooth Solomon Seal	*Polygonatum biflorum*	0.72	23	0.8	a	0.9	a	0.5	a	0.4	0.8360
Sulfur Cinquefoil	*Potentilla recta*	0.70	26	0.6	a	0.4	a	1.2	a	0.4	0.9154
Bladder Campion	*Silene latifolia*	0.67	27	0.0	a	0.8	a	1.1	a	0.5	0.0593
Tall Goldenrod	*Solidago altissima*	0.62	17	0.0	a	1.1	a	0.7	a	0.6	0.1950
Red Clover	*Trifolium pratense*	0.59	15	0.2	a	0.5	a	1.1	a	0.6	0.4795
Hairy Carrionflower	*Smilax mollis*	0.57	17	0.9	a	0.5	a	0.3	a	0.4	0.5070
Yellow Rocket	*Barbarea vulgaris*	0.56	25	0.1	a	0.6	a	0.9	a	0.3	0.1233
Longstyle Sweet Cicily	*Ozmorhiza longistylis*	0.47	21	0.4	a	0.3	a	0.7	a	0.3	0.6499
Field/Prairie Thistle	*Cirsium discolor*	0.47	31	0.1	a	0.7	a	0.6	a	0.2	0.2105

Wild Lettuce	*Lactuca virosa*	0.47	21	0.9	a	0.5	a	0.1	a	0.4	0.4122
Black-Seeded Plantain	*Plantago rugelii*	0.46	20	0.0	a	0.5	a	0.9	a	0.3	0.1773
Sky Blue Aster	*Symphyotrichum oolentangiense*	0.42	20	0.2	a	0.3	a	0.8	a	0.3	0.3691
Late Horse Gentian	*Triosteum perfoliatum*	0.40	8	0.3	a	0.6	a	0.3	a	0.3	0.4497
Ragweed, Giant	*Ambrosia trifida*	0.40	13	0.8	a	0.1	a	0.2	a	0.5	0.6872
Common Mullien	*Verbascum thapsus*	0.35	13	0.0	a	0.4	a	0.7	a	0.2	0.0553
Mayapple	*Podophyllum peltatum*	0.35	4	0.2	a	0.7	a	0.2	a	0.4	0.8493
Virginia Ground Cherry	*Physalis virginiana*	0.33	11	0.2	a	0.3	a	0.6	a	0.3	0.3415
Honewort	*Cryptotaenia canadensis*	0.32	20	0.6	a	0.2	a	0.1	a	0.2	0.8350
Crown Vetch	*Securigera varia*	0.31	1	0.0	a	0.0	a	0.9	a	0.5	0.4096
Tall Cinquefoil	*Potentilla arguta*	0.31	18	0.3	a	0.3	a	0.4	a	0.2	0.6048
Robin's Plantain	*Erigeron pulchellus*	0.31	18	0.4	a	0.4	a	0.1	a	0.2	0.1457
Indian Hemp	*Apocynum cannabinum*	0.31	8	0.6	a	0.0	a	0.3	a	0.3	0.4694
Long/Lance Leaf Goldenrod	*Euthamia graminifolia*	0.30	7	0.4	a	0.0	a	0.5	a	0.2	0.6476
American Vetch	*Vicia americana*	0.30	12	0.3	a	0.4	a	0.2	a	0.2	0.4894
Bird's Foot Violet	*Viola pedata*	0.25	12	0.4	a	0.3	a	0.0	a	0.2	0.1755
Old Field Cinquefoil	*Potentilla simplex*	0.23	10	0.1	a	0.0	a	0.6	a	0.2	0.0840
American Cow Parsnip	*Heracleum sphondylium ssp montanum*	0.23	1	0.7	a	0.0	a	0.0	a	0.4	0.4096
Rough Cinquefoil	*Potentilla norvegica (running)*	0.23	5	0.5	a	0.2	a	0.0	a	0.2	0.3304
Ostrich Fern	*Matteuccia struthiopteris*	0.22	4	0.0	a	0.5	a	0.2	a	0.2	0.2254
Wood Nettle	*Laportea canadensis*	0.19	6	0.2	a	0.4	a	0.0	a	0.2	0.6433
Purple Stemmed Aster	*Symphyotrichum puniceum*	0.19	10	0.2	a	0.3	a	0.1	a	0.2	0.6336

Wild Carrot	*Daucus carota*	0.18	9	0.3	a	0.0	a	0.2	a	0.2	0.4827
Early Buttercup	*Ranunculus fasicularis*	0.18	19	0.1	a	0.3	a	0.1	a	0.1	0.6265
Yellow Wood Sorrel	*Oxalis stricta*	0.17	18	0.3	a	0.2	a	0.1	a	0.1	0.1736
Golden Alexander	*Zizia aurea*	0.17	3	0.0	a	0.2	a	0.3	a	0.2	0.4080
St John's Wort	*Hypericum pyramidatum*	0.16	12	0.1	a	0.3	a	0.2	a	0.1	0.4156
White Clover	*Trifolium repens*	0.16	7	0.2	a	0.1	a	0.3	a	0.2	0.5503
Creeping Charlie	*Glechoma hederacea*	0.16	2	0.0	a	0.2	a	0.3	a	0.2	0.6243
Wood Anemone	*Anemone quinquefolia*	0.15	6	0.4	a	0.0	a	0.1	a	0.1	0.2588
Smooth Ground Cherry	*Physalis subglabrata*	0.15	11	0.3	a	0.1	a	0.0	a	0.1	0.4573
Fringed Loosestrife	*Lysimachia ciliata*	0.14	5	0.2	a	0.2	a	0.0	a	0.1	0.2949
Common Milkweed	*Asclepias syriaca*	0.14	5	0.2	a	0.2	a	0.1	a	0.1	0.8236
Prairie Buttercup	*Ranunculus rhomboideus*	0.13	9	0.0	a	0.1	a	0.0	a	0.1	0.1448
Wild Yam	*Dioscoria villosa*	0.13	4	0.0	a	0.2	a	0.2	a	0.2	0.4096
Culver's Root	*Veronicastrum virginicum*	0.13	4	0.1	a	0.0	a	0.3	a	0.2	0.5147
Starry Solomon's Seal	*Maianthemum stellatum*	0.12	3	0.0	a	0.3	a	0.0	a	0.2	0.5702
Stiff Goldenrod	*Solidago rigidum*	0.11	2	0.2	a	0.2	a	0.0	a	0.1	0.6243
Field Pussytoes	*Antennaria neglecta*	0.11	2	0.0	a	0.0	a	0.3	a	0.2	0.6253
Pea Vine Lathyrus	*Lathyrus latifolius*	0.08	4	0.2	a	0.0	a	0.0	a	0.1	0.5240
Hog Peanut	*Amphicarpaea bracteata*	0.08	9	0.1	a	0.1	a	0.1	a	0.0	0.7121
Curly Dock	*Rumex crispus*	0.08	4	0.0	a	0.0	a	0.2	a	0.1	0.3010
Virginia Waterleaf	*Hydrophyllum virginianum*	0.08	4	0.3	a	0.0	a	0.0	a	0.1	0.4096
Yarrow	*Achillea millefolium*	0.07	8	0.0	a	0.1	a	0.1	a	0.1	0.5085
White Arrow-leaf Aster	*Symphyotrichum urophyllum*	0.07	8	0.0	a	0.0	a	0.2	a	0.1	0.0897
Eastern Black Nightshade	*Solanum ptycanthum*	0.07	8	0.2	a	0.0	a	0.0	a	0.1	0.0885

Columbine	*Aquilegia canadensis*	0.07	8	0.0	a	0.1	a	0.1	a	0.0	0.4455
Deptford Pink	*Dianthus armeria*	0.07	3	0.0	a	0.1	a	0.2	a	0.1	0.5728
Plumeless Thistle	*Carduus acanthoides*	0.06	2	0.0	a	0.0	a	0.2	a	0.1	0.6253
Figwort	*Scrophularia marilandica*	0.06	1	0.0	a	0.2	a	0.0	a	0.1	0.4096
Michigan Lily	*Lilium michiganense*	0.06	1	0.0	a	0.2	a	0.0	a	0.1	0.4096
Nodding/Musk Thistle	*Carduus nutans*	0.06	1	0.2	a	0.0	a	0.0	a	0.1	0.4096
Japanese Hedge Parsley	*Torilis japonica*	0.06	1	0.2	a	0.0	a	0.0	a	0.1	0.4096
Orange Jewelweed	*Impatiens capensis*	0.05	5	0.1	a	0.0	b	0.0	b	0.0	0.0390
Jack in the Pulpit	*Arisaema triphyllum*	0.05	5	0.1	a	0.0	a	0.0	a	0.1	0.6561
Ragweed, Common	*Ambrosia artemisiifolia*	0.05	5	0.1	a	0.0	a	0.1	a	0.0	0.8208
Lambsquarters	*Chenopodium album*	0.04	4	0.0	a	0.1	a	0.0	a	0.0	0.7843
Spiderwort	*Tradescantia ohiensis*	0.03	3	0.0	a	0.0	a	0.1	a	0.0	0.4096
Pale Smartweed	*Persicaria lapathifolia*	0.03	3	0.0	a	0.0	a	0.1	a	0.0	0.4096
Tall thimbleweed	*Anemone virginiana*	0.02	2	0.0	a	0.0	a	0.0	a	0.0	0.6243
Calico Aster	*Symphyotrichum lateriflorum*	0.02	2	0.0	a	0.0	a	0.0	a	0.0	0.6243
False Lily-of-the-valley	*Maianthemum canadense*	0.02	2	0.0	a	0.0	a	0.0	a	0.0	0.6253
Upright Carrionflower	*Smilax ecirrhata*	0.02	2	0.0	a	0.0	a	0.0	a	0.0	0.6253
Wild Onion	*Allium canadense*	0.02	2	0.0	a	0.1	a	0.0	a	0.0	0.1936
Little leaf buttercup	*Ranunculus arborvitus*	0.01	1	0.0	a	0.0	a	0.0	a	0.0	0.4096
Field Bindweed	*Convulvulus arvensis*	0.01	1	0.0	a	0.0	a	0.0	a	0.0	0.4096
Yellow Coneflower	*Ratibida pinnata*	0.01	1	0.0	a	0.0	a	0.0	a	0.0	0.4096
Black Eyed Susan	*Rudbeckia hirta*	0.01	1	0.0	a	0.0	a	0.0	a	0.0	0.4096
Goats Beard	*Tragopogon dubius*	0.01	1	0.0	a	0.0	a	0.0	a	0.0	0.4096
Water Hemp	*Amaranthus rudis*	0.01	1	0.0	a	0.0	a	0.0	a	0.0	0.4096

Shepherd's Purse	*Capsella bursa-pastoris*	0.01	1	0.0	a	0.0	a	0.0	a	0.0	0.4096
White Sweet clover	*Melilotus alba*	0.00	0	0.0	a	0.0	a	0.0	a	0.0	--

[1] Mixed model means and MSE associated with comparison of treatment main-effects means.

[2] Mixed model ranked *P* value associated with treatment *F-test*.

[3] Percent cover per 1 square meter averaged from 270 quadrats, 90 per treatment

-- No values

Table 10. 2014 Graminoid Species list ordered by mean % cover, with count of quadrats found, and cover by treatment

				2014 Mean % Cover by treatment [1]							
Common Name	**Scientific Name**	**% Cover [3]**	**Count**	**Control**		**Light**		**Heavy**		**MSE**	***P* value[2]**
Kentucky Bluegrass	*Poa pratensis*	7.19	91	6.9	a	5.2	a	9.4	a	2.5	0.5076
Virginia Wild Rye	*Elymus virginicus*	2.17	86	2.5	a	2.1	a	1.9	a	1.2	0.6589
Pennsylvania Sedge	*Carex* spp.	1.56	48	1.9	a	2.2	a	0.6	a	0.9	0.2436
Reed Canarygrass	*Phalaris arundinacea*	0.75	13	0.5	a	1.4	a	0.4	a	0.6	0.3316
Fringed Brome	*Bromus ciliatus*	0.72	11	0.0	b	1.0	ab	1.2	a	0.7	0.0208
Sedge spp, type 1	*Carex* spp.	0.47	31	0.5	a	0.5	a	0.5	a	0.2	0.7195
Sedge spp, type 2	*Carex* spp.	0.44	32	0.4	a	0.8	a	0.1	a	0.2	0.1494
Quackgrass	*Elytrigia repens*	0.19	5	0.2	a	0.2	a	0.2	a	0.2	0.8120
Smooth Brome	*Bromus inermis*	0.15	6	0.0	a	0.3	a	0.2	a	0.2	0.4248
Timothy	*Phleum pratense*	0.14	5	0.0	a	0.3	a	0.2	a	0.2	0.1297
Orchardgrass	*Dactylis glomerata*	0.13	4	0.2	a	0.0	a	0.2	a	0.1	0.7836

Tall Fescue	*Festuca arundinacea*	0.06	7	0.1	a	0.1	a	0.1	a	0.0	0.8646
Indiangrass	*Sorghastrum nutans*	0.06	1	0.0	a	0.2	a	0.0	a	0.1	0.4069
Big Bluestem	*Andropogon gerardii*	0.06	1	0.0	a	0.2	a	0.0	a	0.1	0.4069
Panicum	*Panicum* spp.	0.01	1	0.0	a	0.0	a	0.0	a	0.0	0.4069

1 Mixed model means and MSE associated with comparison of treatment main-effects means.

2 Mixed model ranked *P* value associated with treatment *F*-test.

3 Percent cover per 1 square meter averaged from 270 quadrats, 90 per treatment

- No values

-

Table 11. 2014 Woody Species list ordered by mean % cover, with count of quadrats found, and cover by treatment

				2014 Mean % Cover by treatment [1]							
Common Name	**Scientific Name**	**% Cover[3]**	**Count**	**Control**		**Light**		**Heavy**		**95 % CI**	***P* value[2]**
American Basswood	*Tilia americana*	10.06	85	12.1	a	11.4	a	6.7	a	22.9	0.3366
Slippery Elm	*Ulmus rubra*	8.96	106	8.3	a	10.5	a	8.1	a	17.4	0.3052
Bur Oak	*Quercus macrocarpa*	7.54	55	5.5	a	10.1	a	7.0	a	21.6	0.2480
Black Raspberry	*Rubus occidentalis*	7.44	153	10.0	a	8.4	a	4.0	b	10.1	0.0173
Virginia Creeper	*Parthenocissus quinquefolia*	7.24	138	5.8	a	8.3	a	7.7	a	11.5	0.1170
Grey Dogwood	*Cornus racemosa*	6.34	80	3.8	a	8.9	a	6.3	a	15.4	0.0721

Common Prickly Ash	*Zanthoxylum americanum*	4.63	88	4.1	a	3.5	a	6.3	a	12.0	0.6012
Missouri Gooseberry	*Ribes missouriense*	4.47	91	3.9	a	3.8	a	5.7	a	9.1	0.3569
River Bank Grape	*Vitis riparia Michx*	3.76	91	3.8	a	4.5	a	3.0	a	6.9	0.3260
Wild Black Cherry	*Prunus serotina*	3.73	36	5.6	a	3.2	a	2.4	a	14.2	0.4067
Honeyscukle	*Lonicera spp.*	3.06	51	2.4	a	2.7	a	4.1	a	9.9	0.9972
Poison Ivy	*Toxicodendron radicans*	2.96	32	1.3	a	3.6	a	4.0	a	11.0	0.4512
Red Raspberry	*Rubus idaeus*	2.93	58	3.8	a	2.7	a	2.3	a	7.5	0.5645
Eastern Black Walnut	*Juglans nigra*	2.68	19	3.0	a	2.2	a	2.8	a	13.1	0.6805
American Hazelnut	*Corylus americana*	2.53	33	1.8	a	4.1	a	1.8	a	9.5	0.6926
Quaking Aspen	*Populus tremuloides*	2.34	34	1.9	a	2.3	a	2.8	a	10.0	0.8184
Chokecherry	*Prunus virginiana*	2.33	40	1.9	a	2.7	a	2.3	a	8.1	0.8864
Blackberry	*Rubus allegheniensis*	2.33	62	2.2	a	2.6	a	2.2	a	5.4	0.8733
Shagbark Hickory	*Carya ovata*	1.66	26	2.0	a	1.9	a	1.1	a	7.1	0.9413
Butternut	*Juglans cinerea*	1.31	8	0.0	a	2.0	a	1.9	a	10.0	0.1842
Smooth Sumac	*Rhus glabra*	1.27	32	1.6	a	1.4	a	0.8	a	4.7	0.4726
Nannyberry	*Viburnum lentago*	1.08	15	0.7	a	2.1	a	0.4	a	7.0	0.4256
American Plum	*Prunus americana*	1.03	26	1.1	a	0.4	a	1.6	a	4.2	0.3189
Hawthorn	*Crataegus spp.*	0.94	26	1.4	a	1.0	a	0.4	a	3.7	0.4493
Downy Arrowwood	*Viburnum rafinesqueanum*	0.84	16	0.4	a	1.3	a	0.8	a	3.9	0.5550

Elderberry	*Sambucus canadensis*	0.57	4	1.7	a	0.0	a	0.0	a	5.7	0.4096
Boxelder	*Acer negundo*	0.53	9	1.0	a	0.5	a	0.1	a	5.4	0.8088
Black Oak	*Quercus velutina*	0.48	4	0.0	a	0.0	a	1.4	a	5.3	0.8082
American Elm	*Ulmus americana*	0.42	2	0.0	a	0.0	a	1.3	a	5.4	0.4096
Autumn Olive	*Elaeagnus umbellata*	0.42	10	0.4	a	0.2	a	0.6	a	2.9	0.9186
Multiflora Rose	*Rosa multiflora*	0.33	6	0.5	a	0.2	a	0.3	a	2.5	0.9999
Wild Rose	*Rosa spp.*	0.32	15	0.0	a	0.4	a	0.6	a	1.9	0.1056
Summer Grape	*Vitis aestivalis*	0.13	4	0.1	a	0.3	a	0.0	a	1.7	0.4096
Willow	*Salix spp.*	0.11	2	0.0	a	0.3	a	0.0	a	1.7	0.1946
Apple	*Malus spp.*	0.06	2	0.0	a	0.0	a	0.2	a	0.9	0.1946
Mulberry	*Morus spp.*	0.06	1	0.2	a	0.0	a	0.0	a	0.9	0.4096
Hophornbeam	*Ostrya virginiana*	0.06	1	0.2	a	0.0	a	0.0	a	0.9	0.4096
Northern Red Oak	*Quercus rubra*	0.05	5	0.0	a	0.1	a	0.1	a	0.3	0.8200
Native Honeysuckle	*Lonicera dioica L.*	0.02	2	0.1	a	0.0	a	0.0	a	0.2	0.4096
Staghorn Sumac	*Rhus typhina*	0.01	1	0.0	a	0.0	a	0.0	a	0.2	0.4096
Clematis Vine	*Clematis spp.*	0.01	1	0.0	a	0.0	a	0.0	a	0.2	0.4096
Sugar Maple	*Acer saccharum Marsh.*	0.00	0	--	--	--	--	--	--		--
Hackberry	*Celtis occidentalis*	0.00	0	--	--	--	--	--	--		--
Red Osier Dogwood	*Cornus sericea*	0.00	0	--	--	--	--	--	--		--
Common Buckthorn	*Rhamnus cathartica*	0.00	0	--	--	--	--	--	--		--
Lady Fern	*Athyrium filix-femina*	0.00	0	--	--	--	--	--	--		--

Cranberry Viburnum	*Viburnum trilobum*	0.00	0	--	--	--	--	--	--	--
Ash	*Fraxinus spp*	0.00	0	--	--	--	--	--	--	--

1 Mixed model means and 95% CI associated with comparison of treatment main-effects means.

2 Mixed model ranked *P* value associated with treatment *F*-test.

3 Percent cover per 1 square meter averaged from 270 quadrats, 90 per treatment

-- No values

Table 12. Woody stem counts for all years by treatment and grouping

		Treatment[1]							
Group	**Year**	**Control**		**Light**		**Heavy**		**SE**	***P* value[2]**
Alive	2011	34.30	a	33.15	a	33.15	a	6.3992	0.9755
	2012	--	--	--	--	--	--	--	--
	2014	53.52	a	59.25	a	51.47	a	6.5911	0.3688
Dead	2014	8.50	b	9.27	b	16.42	a	1.8174	0.0185
Clonal Alive	2011	4.30	a	4.85	a	6.35	a	2.0201	0.4154
	2012	--	--	--	--	--	--	--	--
	2014	31.75	a	32.43	a	28.43	a	4.4312	0.7989
Clonal Dead	2014	7.73	b	7.43	b	13.57	a	1.7825	0.0264
Aggressive Alive	2011	1.40	a	0.80	a	0.50	a	0.6630	0.7155
	2012	--	--	--	--	--	--	--	--
	2014	5.32	a	5.30	a	8.27	a	1.5462	0.2239
Aggressive Dead	2014	0.23	ab	0.07	b	0.80	a	0.1836	0.0492
Non-Clonal Alive	2011	6.55	a	8.05	a	4.70	a	1.5982	0.5199

	2012	--	--	--	--	--	--	--	--
	2014	21.77	a	26.82	a	23.03	a	5.1225	0.6823
Non-Clonal Dead	2014	0.08	b	1.83	ab	2.85	a	0.6912	0.0118
Rubus & Ribes Alive	2011	20.10	a	13.50	a	17.70	a	4.4598	0.3251
	2012	--	--	--	--	--	--	--	--
	2014	23.05	a	16.70	a	14.27	a	3.7123	0.1313
Vines	2011	1.70	a	3.30	a	2.25	a	0.9509	0.5332
	2012	5.37	a	8.18	a	8.07	a	1.5875	0.327
	2014	--	--	--	--	--	--	--	--

[1] Mixed model means and SE associated with comparison of treatment main-effects means.

[2] Mixed model ranked *P* value associated with treatment *F*-test.

-- No values

Table 13. Species counts for all years by treatment and grouping

		Treatment[1]							
Group	**Year**	**Control**		**Light**		**Heavy**		**SE**	***P* value[2]**
Woody	2011	6.25	a	6.60	a	5.70	a	0.811	0.5506
	2012	--	--	--	--	--	--	--	--
	2014	5.06	a	6.03	a	5.24	a	0.613	0.1934
Total Herbaceous	2011	2.55	a	2.45	a	2.15	a	0.417	0.6765
	2012	--	--	--	--	--	--	--	--
	2014	8.97	b	10.49	a	10.63	a	0.672	0.0096
Forbs	2011	2.55	a	2.20	a	2.00	a	0.381	0.5044
	2012	--	--	--	--	--	--	--	--
	2014	4.37	b	8.58	ab	9.04	a	0.535	0.0180

Graminoids	2011	0.00	a	0.25	a	0.15	a	0.102	0.1588
	2012	0.76	a	0.84	a	0.98	a	0.149	0.2181
	2014	1.60	a	1.91	a	1.59	a	0.199	0.4184
Basal Forbs	2011	4.80	a	4.05	a	4.15	a	0.616	0.5678
	2012	3.63	a	3.59	a	4.14	a	0.307	0.2650
	2014	3.51	a	3.89	a	4.07	a	0.271	0.3411
Invasive Forbs	2011	0.90	a	0.80	a	0.65	a	0.207	0.6243
	2012	0.70	a	0.88	a	0.86	a	0.100	0.2805
	2014	110.32	b	136.13	ab	160.06	a	11.902	0.0076
Partial Shade Forbs	2011	5.60	a	5.10	a	5.20	a	0.586	0.8921
	2012	1.54	a	1.76	a	1.92	a	0.184	0.2480
	2014	3.70	a	4.32	a	4.08	a	0.275	0.1312
Shade Forbs	2011	2.10	a	2.10	a	2.00	a	0.216	0.9116
	2012	1.98	a	2.42	a	2.38	a	0.345	0.2243
	2014	2.40	a	2.76	a	2.56	a	0.209	0.4726
Sun-loving Forbs	2011	1.50	a	1.55	a	1.20	a	0.344	0.4621
	2012	1.54	a	1.76	a	1.92	a	0.184	0.2480
	2014	2.13	a	2.41	a	2.33	a	0.177	0.2320
Upright Forbs	2011	5.25	a	5.65	a	5.05	a	0.570	0.5367
	2012	4.71	a	5.27	a	5.53	a	0.288	0.1140
	2014	3.86	b	4.69	ab	4.98	a	0.434	0.0114
Invasive Graminoids	2011	0.00	a	0.10	a	0.00	a	0.040	0.1836
	2012	0.01	a	0.10	a	0.02	a	0.033	0.1809
	2014	0.06	a	0.10	a	0.04	a	0.027	0.3370
Part Shade Graminoids	2011	1.01	a	1.05	a	0.75	a	0.201	0.2832
	2012	0.25	a	0.36	a	0.34	a	0.076	0.2544
	2014	0.61	a	4.89	a	0.52	a	0.126	0.5239
Shade Graminoids	2011	0.00	a	0.05	a	0.00	a	0.029	0.4096

	2012	0.07	a	0.01	a	0.01	a	0.026	0.2576
	2014	0.61	a	4.89	a	0.51	a	0.127	0.5314
Sun-loving Graminoids	2011	0.00	a	0.15	a	0.15	a	0.087	0.2536
	2012	0.22	a	0.36	a	0.34	a	0.067	0.1831
	2014	0.61	a	0.49	a	0.41	a	0.126	0.2892

[1] Mixed model means and SE associated with comparison of treatment main-effects means.

[2] Mixed model ranked *P* value associated with treatment *F*-test.

-- No values

Table 14. Species mean % cover for all years by treatment and grouping

		Treatment[1]							
Group	**Year**	**Control**		**Light**		**Heavy**		**SE**	***P* value[2]**
Shrubs	2011	36.06	a	40.99	a	37.60	a	5.650	0.7417
	2012	58.34	a	61.48	a	52.84	a	5.579	0.3122
	2014	62.30	a	58.19	ab	44.94	b	6.400	0.0265
Total Herbaceous	2011	9.50	a	15.13	a	9.13	a	3.002	0.8675
	2012	--	--	--	--	--	--	--	--
	2014	92.29	b	104.64	ab	113.78	a	12.754	0.0436
Graminoids	2011	0.00	a	6.50	a	0.38	a	2.378	0.1453
	2012	2.64	a	3.22	a	3.29	a	0.687	0.2847
	2014	17.01	a	21.17	a	21.10	a	5.016	0.7440
Forbs	2011	9.50	a	8.63	a	8.75	a	2.057	0.6195
	2012	--	--	--	--	--	--	--	--
	2014	75.52	a	83.68	a	92.88	a	9.996	0.1118
Invasive Forbs	2011	3.50	a	3.88	a	3.50	a	1.664	0.7531
	2012	3.25	a	4.92	a	4.92	a	1.379	0.202

	2014	14.17	b	21.68	ab	27.49	a	4.332	0.0313
Sun-loving Forbs	2011	6.25	a	6.38	a	4.88	a	1.943	0.5643
	2012	6.06	a	7.67	ab	9.64	b	1.284	0.0384
	2014	24.12	a	25.09	a	29.46	a	4.794	0.4026
Partial Shade Forbs	2011	26.88	a	22.63	a	22.63	a	4.039	0.5140
	2012	6.06	a	7.67	ab	9.64	b	1.284	0.0384
	2014	40.38	a	41.63	a	42.10	a	6.569	0.7354
Shade Forbs	2011	12.50	a	13.13	a	14.00	a	4.534	0.9548
	2012	13.42	a	10.69	a	13.06	a	3.751	0.3731
	2014	28.58	a	28.89	a	27.44	a	5.985	0.6738
Basal Forbs	2011	27.88	a	22.25	a	28.50	a	5.127	0.4723
	2012	28.26	a	23.08	a	26.51	a	4.921	0.3788
	2014	38.91	a	37.43	a	44.59	a	3.349	0.2707
Upright Forbs	2011	21.75	a	21.63	a	17.50	a	2.481	0.2789
	2012	23.00	a	24.14	a	24.40	a	1.992	0.7883
	2014	36.86	a	46.46	a	48.53	a	7.752	0.0847
Invasive Graminoids	2011	0.00	a	3.75	a	0.00	a	1.490	0.1836
	2012	0.17	a	0.67	a	0.06	a	0.246	0.1808
	2014	0.84	a	1.74	a	0.67	a	0.723	0.3461
Sun-loving Graminoids	2011	0.00	a	2.75	a	0.38	a	1.172	0.2410
	2012	0.83	a	1.44	a	1.26	a	0.336	0.1797
	2014	4.81	a	4.78	a	2.91	a	1.450	0.3808
Part Shade Graminoids	2011	4.63	a	9.75	a	1.88	a	1.922	0.1184
	2012	0.32	a	0.03	a	0.03	a	0.140	0.2576
	2014	4.81	a	5.58	a	4.18	a	1.832	0.7585

[1] Mixed model means and SE associated with comparison of treatment main-effects means.

[2] Mixed model ranked *P* value associated with treatment *F*-test.

-- No values

Table 15. Percent brush cover per coverboard band for all years by treatment and grouping

Band	Year	Treatment[1]						SE	*P* value[2]
		Control		Light		Heavy			
Band 5 (2-2.5 m)	2011	15.61	a	19.00	a	18.15	a	4.807	0.9771
	2012	31.46	a	31.49	a	24.07	a	7.605	0.1376
	2014	48.32	a	33.94	ab	16.70	b	8.100	0.0369
Band 4 (1.5-2 m)	2011	19.55	a	27.26	a	23.49	a	5.206	0.6906
	2012	53.34	a	41.10	a	39.13	a	7.772	0.1415
	2014	53.28	a	42.00	a	25.22	a	8.750	0.0647
Band 3 (1-1.5 m)	2011	24.55	a	34.65	a	31.79	a	6.686	0.4595
	2012	56.09	a	50.79	a	45.77	a	8.489	0.6081
	2014	55.40	a	50.78	ab	35.90	b	8.570	0.0474
Band 2 (.5-1 m)	2011	50.96	a	49.78	a	47.79	a	9.122	0.9785
	2012	78.57	a	76.64	a	70.83	a	5.572	0.3286
	2014	71.61	a	74.49	a	62.30	a	6.400	0.2284
Band 1 (0-.5 m)	2011	69.61	a	74.25	a	66.80	a	6.990	0.6454
	2012	87.99	a	91.83	ab	84.24	b	3.424	0.0293
	2014	82.90	a	89.81	a	84.66	a	3.100	0.2614

[1] Mixed model means and SE associated with comparison of treatment main-effects means.

[2] Mixed model ranked *P* value associated with treatment *F*-test.

-- No values

Table 16. Species counts for all years by treatment and grouping

Group	Year	Treatment[1] Control		Light		Heavy		SE	*P* value[2]
Soil Compaction (cm)	2012	11.70	--	12.30	--	12.60	--	--	--
	2014	31.87	a	31.81	a	30.93	a	3.302	0.7644
PAR	2012	17.83	a	12.19	a	9.82	a	2.554	0.2256
	2014	4.61	a	3.29	a	3.63	a	0.520	0.1141
Litter Depth (cm)	2011	5.77	a	4.83	a	5.83	a	0.641	0.5652
	2012	34.75	a	32.83	a	22.66	a	5.080	0.0559
	2014	2.99	a	3.14	a	2.74	a	0.235	0.7451
Shrub Height (m)	2011	0.91	a	0.93	a	1.01	a	0.089	0.6682
	2012	--	--	--	--	--	--	--	--
	2014	1.79	a	1.65	ab	1.35	b	0.110	0.0184

[1] Mixed model means and SE associated with comparison of treatment main-effects means.

[2] Mixed model ranked *P* value associated with treatment *F*-test.

-- No values

Table 17. Species grouping % cover and counts for all years by treatment and grouping

Group	Year	Treatment[1] Control		Light		Heavy		SE	*P* value[2]
Carex Count	2012	0.72	a	0.66	a	0.51	a	0.122	0.2338
Carex Cover	2012	2.54	a	3.42	a	1.43	a	0.585	0.1404
Native Forb Count	2012	6.44	a	6.93	a	7.29	a	0.369	0.1274
Native Forb Cover	2012	42.40	a	38.69	a	41.18	a	4.959	0.7135
Invasive Forb Count	2012	1.28	a	1.27	a	1.67	a	0.130	0.0721
Invasive Forb Cover	2012	6.22	a	5.50	a	7.23	a	1.160	0.1519
Pruka List Forb Count	2014	0.27	a	0.28	a	0.16	a	0.076	0.1678
Pruka List Forb Cover	2014	1.47	a	1.67	a	1.31	a	0.589	0.2254
Graminoid Clonal Count	2014	0.60	a	0.68	a	0.47	a	0.136	0.4189
Graminoid Clonal Cover	2014	10.20	a	10.21	a	11.50	a	2.993	0.6836
Native Graminoid Count	2012	1.17	a	0.94	a	0.98	a	0.111	0.3153
Native Graminoid Cover	2012	3.81	a	3.89	a	3.00	a	0.607	0.4738
NonInvasive Graminoid Count	2012	0.23	a	0.41	a	0.35	a	0.067	0.1045
Noninvasive Graminoid Cover	2012	0.89	a	1.58	a	1.29	a	0.347	0.1192
Pruka List Graminoid Count	2014	0.36	a	0.27	a	0.33	a	0.104	0.4604
Pruka List Graminoid Cover	2014	2.70	a	2.24	a	2.26	a	1.295	0.6589
Shade Graminoid Count	2011	0.00	a	0.13	a	0.00	a	0.072	0.4096
Shade Graminoid Count	2012	1.06	a	1.44	a	1.26	a	0.382	0.2493
Shade Graminoid Count	2014	4.81	a	5.58	a	4.14	a	1.834	0.7479
Invasive Herbaceous Cover	2012	3.95	a	4.94	a	4.87	a	1.337	0.8474
Invasive Herbaceous Count	2012	0.80	a	0.90	a	0.84	a	0.068	0.8447
Top-killed Rubus and Ribes	2014	7.33	a	6.23	a	10.38	a	1.583	0.1203

Clonal Stem Count	2012	1.23	a	1.72	a	1.62	a	0.696	0.7063
NonClonal Stem Count	2012	8.30	a	8.33	a	7.70	a	1.445	0.4927
Oak Stem Count	2012	0.25	a	0.50	a	0.55	a	0.217	0.6109
Rubus and Ribes Stem Count	2012	30.33	a	22.88	a	25.33	a	4.359	0.1639
Shrub Stem Count	2012	13.08	a	17.55	a	19.63	a	3.233	0.4996
Tilia Stem Count	2012	4.47	a	9.02	a	12.02	a	2.256	0.2791
Total Stem Count	2012	50.40	a	53.23	a	55.55	a	6.859	0.3767
Clonal Woody Count	2014	1.80	a	2.12	a	1.91	a	0.275	0.3909
Clonal Woody Cover	2014	29.54	a	33.09	a	27.16	a	5.643	0.5743
Invasive Woody Count	2014	0.26	a	0.24	a	0.24	a	0.059	0.9358
Invasive Woody Cover	2014	4.01	a	3.47	a	5.47	a	1.286	0.9433
Part Shade Woody Count	2014	2.76	a	3.11	a	2.78	a	0.268	0.2912
Part Shade Woody Cover	2014	50.50	a	57.60	a	47.50	a	6.728	0.5662
Shade Woody Count	2014	2.76	a	3.11	a	2.78	a	0.268	0.3137
Shade Woody Cover	2014	41.06	a	44.89	a	38.73	a	5.662	0.6605
Sun Woody Count	2014	0.89	a	1.04	a	0.91	a	0.120	0.5480
Sun Woody Cover	2014	13.83	a	18.07	a	13.70	a	3.241	0.3419

[1] Mixed model means and SE associated with comparison of treatment main-effects means.

[2] Mixed model ranked *P* value associated with treatment *F*-test.

-- No values

APPENDIX B:

Tables from Chapter 3.

Table 1. Goat average daily gain (grams) by year and class of goat.

Class	Year	LSMeans	SE	N[2]	DF	*t Value*	*P* Value[1]	Letter Group
Kid	2012	143.2	8.0	34	266	8128.4	<.0001	a
Kid	2011	125.7	7.4	40	266	7738.3	<.0001	a
Kid	2013	78.6	7.4	40	266	4835.3	<.0001	b
Open	2013	72.6	12.9	13	266	2549.2	<.0001	bcd
Yearling	2013	62.9	7.9	35	266	3619.7	<.0001	bc
Open	2011	56.7	13.5	12	266	1909.6	<.0001	bcde
Nursing	2013	37.1	10.2	21	266	1655.6	0.0003	cde
Nursing	2012	18.6	10.4	20	266	807.4	0.0755	de
Nursing	2011	6.0	9.3	25	266	290.3	0.5230	ef
Wether	2011	-0.7	15.5	9	266	-22.7	0.9631	ef
Open	2012	-32.4	8.8	28	266	-1669.2	0.0003	f

[1] Mixed model P value associated with gain *F-test*.

[2] Sample size for each class by year combination, with samples fewer than 6 removed from the analysis

Table 2. Goat average daily gain (grams) by breed and class of goat.

Breed2	Class	LSMeans	SE	N[3]	DF	*t Value*	*P* Value[1]	Letter Group
K	Kid	143.24	7.7	34	251	8441.3	<.0001	a
BS	Kid	130.00	7.9	40	251	7434.4	<.0001	ab
BK	Open	89.40	17.0	7	251	2390.4	<.0001	abc
BKM	Kid	88.77	15.9	8	251	2540.1	<.0001	abc
BK	Kid	81.83	9.0	25	251	4136.8	<.0001	c
BK	Yearling	71.03	18.3	6	251	1759.9	0.0001	abcdef
BKM	Yearling	65.18	9.4	23	251	3161.5	<.0001	cg
BS	Open	56.70	13.0	12	251	1986.7	<.0001	cd
M	Yearling	45.90	18.3	6	251	1138.5	0.0129	cde
BK	Nursing	42.80	10.9	17	251	1782.6	0.0001	cde
BS	Nursing	5.96	9.0	23	251	299.4	0.5071	def
K	Nursing	-7.37	11.2	16	251	-299.4	0.5117	ef
K	Open	-32.38	8.5	28	251	-1732.7	0.0002	f

1 Mixed model P value associated with gain *F-test*.

2 Breeds: K=Kiko, S=Spanish, M=Myotonic, BK=Boer/Kiko, BKM=Boer/Kiko/Myotonic

3 Sample size for each breed by class combination, with samples fewer than 6 removed from the analysis

Table 3. Goat body condition score change by year and class of goat.

Class	Year	LSMeans	SE	N[2]	DF	*t Value*	*P* Value[1]	Letter Group
Kid	2012	0.029	0.116	34	185	0.25	0.8004	bcd
Kid	2013	0.050	0.107	40	185	0.47	0.6411	bc
Nursing	2012	-0.550	0.151	20	185	-3.63	0.0004	d
Nursing	2013	0.857	0.148	21	185	5.8	<.0001	a
Open	2012	0.393	0.128	28	185	3.07	0.0025	ab
Open	2013	0.692	0.188	13	185	3.69	0.0003	ab
Yearling	2013	0.500	0.113	35	185	4.43	<.0001	ab

1 Mixed model P value associated with score change *F-test*.

2 Sample size for each class by year combination, with samples fewer than 6 removed from the analysis

Table 4. Goat FAMACHA anemia score change by year and class of goat.

Class	Year	LSMeans	SE	N[2]	DF	*t Value*	*P* Value[1]	Letter Group
Kid	2011	0.075	0.141	40	267	0.53	0.5959	ab
Kid	2012	0.412	0.153	34	267	2.69	0.0077	a
Kid	2013	-0.400	0.141	40	267	-2.83	0.0050	b
Nursing	2011	-0.200	0.179	25	267	-1.12	0.2641	ab
Nursing	2012	0.300	0.200	20	267	1.50	0.1344	ab
Nursing	2013	0.381	0.195	21	267	1.95	0.0518	ab
Open	2011	0.000	0.258	12	267	0.00	1.0000	ab
Open	2012	-0.143	0.169	28	267	-0.85	0.3983	ab
Open	2013	0.308	0.248	13	267	1.24	0.2155	ab
Wether	2011	-0.222	0.298	9	267	-0.75	0.4562	ab
Yearling	2013	0.306	0.149	35	267	2.05	0.0412	a

[1] Mixed model P value associated with score change F-test.

[2] Sample size for each class by year combination, with samples fewer than 6 removed from the analysis

Table 5. Activity budget (% of time) spent by goats in brush-invaded oak savanna by year.

	Activity budget, % of time [1]			
Item	**2011**	**2012**	**2013**	***P* value[2]**
Eating brush	44.8 (± 2.5) b	53.8 (± 2.5) a	49.6 (± 2.4) ab	0.0033
Eating forbs	4.1 (± 1.0) b	9.4 (± 1.1) a	7.2 (± 1.0) a	<.0001
Eating graminoids	1.6 (± 0.5) b	2.4 (± 0.5) ab	1.7 (± 0.5) a	0.0193
Eating	50.9 (± 2.1) b	65.5 (± 2.1) a	58.4 (± 2.0) b	<.0001
Chewing	3.0 (± 0.8) a	1.1 (± 0.8) a	1.2 (± 0.8) a	0.5543
Laying	7.2 (± 2.4) c	16.5 (± 2.5) b	12.4 (± 2.4) a	<.0001
Mineral	1.8 (± 0.3) a	0.0 (± 0.3) b	1.3 (± 0.3) a	<.0001
Standing	26.4 (± 1.4) a	9.7 (± 1.4) c	17.6 (± 1.3) b	<.0001
Drinking	0.1 (± 0.1) b	0.0 (± 0.1) b	0.3 (± 0.1) a	0.0003
Walking	10.7 (± 0.6) a	7.0 (± 0.7) b	8.6 (± 0.6) a	0.0007
Active	10.7 (± 0.6) a	7.0 (± 0.7) b	8.6 (± 0.6) a	0.0007
Not Active	38.5 (± 2.3) a	27.4 (± 2.3) b	33.0 (± 2.2) a	<.0001

[1] Mixed model means and (±SE) associated with comparison of year main-effects means.

[2] Mixed model ranked *P* value associated with year *F*-test.

Table 6. Activity budget (% of time) spent by goats in brush-invaded oak savanna by time of day.

Item	Morning					Lunch					Afternoon					Evening					*P* value[2]
	Dietary botanical selection, % of time [1]																				
Eating brush	53.9	(±	2.7	)	a	45.6	(±	2.7	)	b	45.9	(±	2.8	)	ab	51.6	(±	2.6	)	ab	0.0174
Eating forbs	7.9	(±	1.1	)	a	6.0	(±	1.1	)	a	6.4	(±	1.1	)	a	7.2	(±	1.1	)	a	0.8206
Eating graminoids	2.0	(±	0.6	)	a	2.2	(±	0.6	)	a	1.2	(±	0.6	)	a	2.1	(±	0.6	)	a	0.4724
Eating	63.7	(±	2.3	)	a	53.7	(±	2.3	)	b	53.5	(±	2.4	)	b	61.1	(±	2.3	)	ab	0.0021
Chewing	1.9	(±	0.8	)	a	2.2	(±	0.8	)	a	1.6	(±	0.9	)	a	1.4	(±	0.8	)	a	0.2963
Laying	8.0	(±	2.7	)	a	12.4	(±	2.7	)	a	16.8	(±	2.7	)	a	11.0	(±	2.6	)	a	0.0822
Mineral	1.1	(±	0.4	)	a	1.1	(±	0.4	)	a	0.7	(±	0.4	)	a	1.3	(±	0.4	)	a	0.4003
Standing	15.9	(±	1.6	)	b	22.0	(±	1.6	)	a	18.9	(±	1.6	)	ab	15.6	(±	1.5	)	ab	0.0178
Drinking	0.1	(±	0.1	)	a	0.1	(±	0.1	)	a	0.2	(±	0.1	)	a	0.2	(±	0.1	)	a	0.6995
Walking	9.2	(±	0.7	)	a	8.4	(±	0.7	)	a	8.1	(±	0.8	)	a	9.3	(±	0.7	)	a	0.6332
Active	319.0	(±	13.9	)	a	304.9	(±	13.9	)	a	294.0	(±	14.6	)	a	312.8	(±	13.6	)	a	0.6332
Not Active	261.3	(±	14.5	)	b	341.4	(±	14.5	)	a	335.6	(±	15.1	)	a	295.1	(±	14.2	)	ab	0.0001

[1] Mixed model means and (±SE) associated with comparison of time of day main-effects means.

[2] Mixed model ranked *P* value associated with time of day *F*-test.

Table 7. Species ordered from most selected to least selected by goats over 3 years at YLWA

Group	Common Name	Scientific Name	Ave % of Diet
Shrub	Dog Wood	*Cornus racemosa*	13.47
Shrub	Prickly Ash	*Zanthoxylum americanum*	7.23
Tree	Linden	*Tilia americana*	6.44
Bramble	Black Raspberry	*Rubus occidentalis*	6.16
Shrub	Choke Cherry	*Prunus virginiana*	6.02
Tree	Elm	*Ulmus americana*	5.13
Shrub	Hazelnut	*Corylus americana*	5.05
Tree	Aspen	*Populus tremuloides*	3.96
Tree	Black Cherry	*Prunus serotina*	3.25
Bramble	Goose berry	*Ribes missouriense*	3.21
Bramble	Black Berry	*Rubus allegheniensis*	2.84
Shrub	Honeysuckle	*Lonicera spp.*	2.41
Vine	Grape	*Vitis riparia Michx*	1.99
Forb	Canada Goldenrod	*Solidago canadensis*	1.80
Tree	Oak	*Quercus spp.*	1.22
Bramble	Multiflora Rose	*Rosa multiflora*	1.21
Bramble	Raspberry	*Rubus idaeus*	1.21
Tree	Hickory	*Carya ovata*	1.09
Shrub	Nanny Berry	*Viburnum lentago*	0.97
Shrub	Hawthorne	*Crataegus spp.*	0.71

Tree	Black Walnut	*Juglans nigra*	0.68
Forb	Canada Thistle	*Cirsium spp.*	0.60
Shrub	Plum	*Prunus americana*	0.57
Forb	Dandelion	*Taraxacum officinale*	0.54
Vine	Poison Ivy	*Toxicodendron radicans*	0.52
Tree	Boxelder	*Acer negundo*	0.36
Shrub	Smooth Sumac	*Rhus glabra*	0.30
Forb	Stinging Nettle	*Urtica dioica*	0.30
Shrub	Crab Apple	*Malus spp.*	0.26
Forb	Sulfur Cinquefoil	*Potentilla recta*	0.24
Forb	Burdock	*Arctium minus*	0.23
Shrub	Willow	*Salix spp.*	0.22
Vine	Virginia Creeper	*Parthenocissus quinquefolia*	0.19
Forb	Parsnip	*Pastinaca sativa*	0.17
Vine	Summer Grape	*Vitis aestivalis*	0.17
Shrub	Autumn Olive	*Elaeagnus umbellata*	0.16
Shrub	Viburnum	*Viburnum trilobum*	0.15
Graminoid	Reed Canary Grass	*Phalaris arundinacea*	0.13
Vine	Cat Briar	*Smilax mollis*	0.13
Forb	Bedstraw	*Galium spp.*	0.11
Bramble	Wild Rose	*Rosa spp.*	0.09
Forb	Clover	*Trifolium pratense*	0.05
Shrub	Arrowwood	*Viburnum rafinesqueanum*	0.05
Forb	Strawberry	*Fragaria virginiana*	0.04
Forb	Aster	*Aster spp.*	0.02
Forb	Yellow Sweet Clover	*Melilotus officinalis*	0.01
Forb	Solomon's Seal	*Maianthemum racemosum*	0.01
Forb	Common Mullein	*Verbascum thapsus*	0.00

Table 8. Botanical composition of goat diets, availability of the botanical type (% cover), and Kulcyznski's Similarity Index (KSI, % similarity) in brush-invaded oak savanna by year.

	Botanical composition, % [1]			
Item	**2011**	**2012**	**2013**	***P* value2**
Dietary botanical selection, % of diet				
Woody	88.9 (± 2.2) a	81.2 (± 2.2) b	83.8 (± 2.0) b	<.0001
Forb	8.2 (± 1.9) b	14.5 (± 1.9) a	13.5 (± 1.8) a	<.0001
Graminoid	2.9 (± 0.9) a	4.3 (± 1.0) a	2.8 (± 0.9) a	0.0355
Botanical Availability, % cover				
Woody	39.2 (± 4.8) c	58.3 (± 4.8) a	45.0 (± 4.8) b	<.0001
Forb	7.1 (± 2.1) c	11.2 (± 2.1) b	49.2 (± 2.1) a	<.0001
Graminoid	2.1 (± 1.1) c	5.8 (± 1.1) b	13.7 (± 1.1) a	<.0001
KSI, % similarity [3]				
Woody	56.4 (± 3.9) c¥	74.6 (± 3.9) a¥	68.5 (± 3.9) b¥	<.0001
Forb	16.5 (± 2.5) b*	33.2 (± 2.6) a¥	34.5 (± 2.3) a#	<.0001
Graminoid	1.1 (± 1.8) b*	10.1 (± 1.9) a∞	14.1 (± 1.7) a∞	<.0001

[1] Mixed model means and (±SE) associated with comparison of year main-effects means.

[2] Mixed model ranked *P* value associated with year *F-test*.

[3] Kulcyznski's Similarity Index (KSI):

* Strong preference (i.e. KSI ≤ 20, selection frequency > availability)
∞ Strong avoidance (i.e. KSI ≤ 20, availability > selection frequency)
¥ Moderate preference (i.e. KSI btwn 21% and 79%, selection frequency > availability)
Moderate avoidance (i.e. KSI btwn 21% and 79%, availability > selection frequency)

Table 9. Botanical composition of goat diets in brush-invaded oak savanna, by plant species

Item	Botanical composition, % of diet [1]																P value2
	2011					2012					2013						***P* value2**
Woody species																	
Trees																	
Acer negundo	0.0	(±	0.3	)	b	0.6	(±	0.3	)	b	0.5	(±	0.3	)	a		0.0025
Carya ovata	1.2	(±	0.5	)	a	0.9	(±	0.5	)	a	1.2	(±	0.4	)	a		0.2587
Juglans nigra	0.5	(±	0.4	)	a	0.3	(±	0.4	)	a	1.2	(±	0.4	)	a		0.4765
Populus tremuloides	3.4	(±	0.9	)	b	3.7	(±	0.9	)	b	4.7	(±	0.9	)	a		<.0001
Prunus serotina	3.2	(±	0.9	)	b	5.4	(±	0.9	)	a	1.4	(±	0.9	)	b		0.0172
Quercus spp.	1.7	(±	0.5	)	a	1.0	(±	0.5	)	a	1.0	(±	0.5	)	a		0.9812
Tilia americana	6.3	(±	1.5	)	a	6.9	(±	1.5	)	a	6.4	(±	1.5	)	a		0.1336
Ulmus americana	6.1	(±	1.1	)	a	7.1	(±	1.1	)	a	2.4	(±	1.1	)	a		0.3013
Vines																	
Parthenocissus quinquefolia	0.1	(±	0.1	)	b	0.5	(±	0.1	)	a	0.1	(±	0.1	)	b		0.0111
Smilax mollis	0.2	(±	0.1	)	a	0.0	(±	0.1	)	a	0.2	(±	0.1	)	a		0.2844

Toxicodendron radicans	0.0	(±	0.3	)	b	0.0	(±	0.3	)	b	1.5	(±	0.3	)	a	<.0001
Vitis aestivalis	0.0	(±	0.1	)	b	0.0	(±	0.1	)	b	0.5	(±	0.1	)	a	<.0001
Vitis riparia Michx	3.1	(±	0.7	)	a	1.1	(±	0.7	)	b	1.7	(±	0.7	)	ab	0.0142
Shrubs																
Cornus racemosa	11.3	(±	1.6	)	b	8.2	(±	1.6	)	b	20.3	(±	1.5	)	a	<.0001
Corylus americana	3.2	(±	1.2	)	b	2.3	(±	1.2	)	b	9.1	(±	1.2	)	a	<.0001
Crataegus spp.	0.9	(±	0.4	)	a	0.8	(±	0.4	)	a	0.4	(±	0.4	)	a	0.3919
Elaeagnus umbellata	0.2	(±	0.2	)	a	0.2	(±	0.2	)	a	0.1	(±	0.2	)	a	0.8641
Lonicera spp.	3.4	(±	0.9	)	a	1.8	(±	0.9	)	a	2.0	(±	0.9	)	a	0.3506
Malus spp.	0.4	(±	0.3	)	a	0.0	(±	0.3	)	a	0.4	(±	0.3	)	a	0.3626
Prunus americana	0.6	(±	0.5	)	a	0.8	(±	0.5	)	a	0.2	(±	0.5	)	a	0.8309
Prunus virginiana	9.8	(±	1.1	)	a	3.1	(±	1.1	)	b	5.0	(±	1.1	)	a	0.0002
Rhus glabra	0.1	(±	0.1	)	b	0.1	(±	0.1	)	b	0.7	(±	0.1	)	a	0.0004
Salix spp.	0.0	(±	0.1	)	b	0.4	(±	0.1	)	a	0.3	(±	0.1	)	ab	0.0433
Viburnum lentago	0.7	(±	0.5	)	b	2.2	(±	0.5	)	a	0.3	(±	0.5	)	b	0.0004
Viburnum rafinesqueanum	0.0	(±	0.1	)	a	0.0	(±	0.1	)	a	0.1	(±	0.1	)	a	0.1845
Viburnum trilobum	0.3	(±	0.2	)	a	0.0	(±	0.2	)	a	0.2	(±	0.2	)	a	0.6349
Zanthoxylum americanum	7.6	(±	3.0	)	b	10.1	(±	3.0	)	a	5.3	(±	3.0	)	ab	0.0545
Brambles																
Ribes missouriense	2.9	(±	0.7	)	b	1.6	(±	0.8	)	b	4.9	(±	0.7	)	a	0.0015
Rosa multiflora	1.7	(±	0.6	)	a	0.9	(±	0.6	)	a	1.1	(±	0.6	)	a	0.5733
Rosa spp.	0.0	(±	0.1	)	b	0.0	(±	0.1	)	b	0.3	(±	0.1	)	a	0.0018

Rubus allegheniensis	1.7 (± 1.3) b	4.1 (± 1.3) a	2.2 (± 1.3) a	0.0006
Rubus idaeus	2.1 (± 0.6) a	0.9 (± 0.6) a	0.7 (± 0.6) a	0.3253
Rubus occidentalis	6.7 (± 1.4) a	4.8 (± 1.4) a	6.9 (± 1.4) a	0.2357
Forb species				
Arctium minus	0.2 (± 0.1) b	0.0 (± 0.1) b	0.5 (± 0.1) a	0.0036
Aster spp.	0.1 (± 0.0) a	0.0 (± 0.0) a	0.0 (± 0.0) a	0.3744
Cirsium spp.	0.1 (± 0.2) a	0.0 (± 0.2) b	1.2 (± 0.2) a	0.0003
Fragaria virginiana	0.1 (± 0.1) a	0.0 (± 0.1) a	0.0 (± 0.0) a	0.6349
Galium spp.	0.2 (± 0.1) a	0.0 (± 0.1) a	0.2 (± 0.1) a	0.635
Maianthemum racemosum	0.0 (± 0.0) a	0.0 (± 0.0) a	0.0 (± 0.0) a	0.3737
Melilotus officinalis	0.0 (± 0.0) a	0.0 (± 0.0) a	0.0 (± 0.0) a	0.3737
Pastinaca sativa	0.2 (± 0.1) a	0.0 (± 0.1) a	0.3 (± 0.1) a	0.0759
Potentilla recta	0.2 (± 0.1) b	0.0 (± 0.2) b	0.5 (± 0.1) a	0.0001
Solidago canadensis	2.9 (± 0.6) a	0.0 (± 0.6) b	2.2 (± 0.6) a	<.0001
Taraxacum officinale	2.5 (± 1.2) b	12.4 (± 1.3) a	6.6 (± 1.2) a	<.0001
Trifolium pratense	0.1 (± 0.1) a	0.0 (± 0.1) a	0.1 (± 0.1) a	0.1336
Urtica dioica	0.2 (± 0.2) ab	0.0 (± 0.2) b	0.6 (± 0.2) a	0.0099
Verbascum thapsus	0.0 (± 0.0) a	0.0 (± 0.0) a	0.0 (± 0.0) a	1.0000
Graminoid species				
Phalaris arundinacea	0.2 (± 0.2) a	0.0 (± 0.2) a	0.2 (± 0.2) a	0.635
Poa spp.	2.4 (± 0.9) b	3.7 (± 0.9) ab	2.6 (± 0.8) a	0.0178

[1] Mixed model means and (±SE) associated with comparison of year main-effects means.

[2] Mixed model ranked *P* value associated with year *F-test*.

Table 10. 2014 Species list, average % cover, count of quadrats where found, and cover by treatment. Ordered by type of plant, then by decreasing average percent cover.

Common Name	Scientific Name	% Cover [3]	Count	2014 Cover by treatment [1] Control		Light		Heavy		MSE	*P* value2
Forb Species											
Dandelion	*Taraxacum officinale*	11.69	237	11.8	a	10.8	a	12.5	a	101.7	0.8045
Wild strawberry	*Fragaria virginiana*	9.57	132	8.3	a	8.7	a	11.8	a	223.6	0.1745
Canada goldenrod	*Solidago canadensis*	6.26	158	6.5	a	6.0	a	6.3	a	82.1	0.9302
Burdock	*Arctium minus*	4.75	63	1.6	a	5.4	a	7.3	a	158.4	0.0698
Clustered black snakeroot	*Sanicula marilandica*	4.31	56	0.6	a	4.8	a	2.3	a	127.2	0.3555
Wild geranium	*Geranium maculatum*	4.04	111	5.1	a	4.0	a	3.0	a	42.0	0.3743
Bedstraw	*Galium* spp.	2.34	149	1.6	a	2.7	a	2.8	a	27.2	0.2314
Canada thistle	*Cirsium arvense*	2.12	65	1.9	a	1.6	a	2.8	a	36.7	0.2531
White avens	*Geum canadense*	1.98	79	1.8	a	1.9	a	2.2	a	20.0	0.9450
Woodland violet	*Viola papilionacea*	1.76	81	1.5	a	1.9	a	1.8	a	27.0	0.9208
Black medic	*Medicago lupulina*	1.70	64	1.8	a	0.8	a	2.6	a	21.1	0.1719
Fleabane daisy	*Erigeron strigosus*	1.31	47	0.2	b	2.2	a	1.5	ab	14.2	0.0256
Chickweed	*Stellaria media*	1.25	45	1.1	a	1.3	a	1.3	a	17.6	0.7907

Bergamot	*Monarda fistulosa*	1.06	25	1.0	a	0.7	a	1.4	a	15.0	0.3616
Bull thistle	*Cirsium vulgare*	1.05	33	0.1	a	1.8	a	1.3	a	13.5	0.0595
Stinging nettle	*Urtica dioica*	1.04	24	0.8	a	1.3	a	0.9	a	43.2	0.6827
Yellow sweet clover	*Melilotus officinalis*	1.00	24	0.7	a	1.2	a	1.1	a	25.2	0.4838
Wild parsnip	*Pastinaca sativa*	0.96	21	0.6	a	1.9	a	0.4	a	34.1	0.4307
Motherwort	*Leonurus cardiaca*	0.87	29	0.3	a	0.9	a	1.4	a	11.5	0.3761
Garlic mustard	*Alliaria petiolata*	0.80	21	0.6	a	0.4	a	1.4	a	14.9	0.3620
Enchanter's nightshade	*Circaea lutetiana*	0.79	65	1.0	a	0.7	a	0.7	a	4.1	0.8416
Naked Flower Tick Trefoil	*Desmodium nudiflorum*	0.77	18	1.0	a	0.5	a	0.8	a	11.5	0.6673
False solomon's seal	*Maianthemum racemosum*	0.73	24	0.8	a	0.9	a	0.5	a	9.0	0.8469
Smooth solomon seal	*Polygonatum biflorum*	0.72	23	0.8	a	0.9	a	0.5	a	8.9	0.8360
Sulfur cinquefoil	*Potentilla recta*	0.70	26	0.6	a	0.4	a	1.2	a	9.1	0.9154
Bladder campion	*Silene latifolia*	0.67	27	0.0	a	0.8	a	1.1	a	7.4	0.0593
Tall goldenrod	*Solidago altissima*	0.62	17	0.0	a	1.1	a	0.7	a	9.2	0.1950
Red clover	*Trifolium pratense*	0.59	15	0.2	a	0.5	a	1.1	a	19.5	0.4795
Hairy carrionflower	*Smilax mollis*	0.57	17	0.9	a	0.5	a	0.3	a	7.4	0.5070
Yellow rocket	*Barbarea vulgaris*	0.56	25	0.1	a	0.6	a	0.9	a	5.9	0.1233
Longstyle sweet cicily	*Ozmorhiza longistylis*	0.47	21	0.4	a	0.3	a	0.7	a	6.3	0.6499
Field/Prairie thistle	*Cirsium discolor*	0.47	31	0.1	a	0.7	a	0.6	a	3.7	0.2105
Wild lettuce	*Lactuca virosa*	0.47	21	0.9	a	0.5	a	0.1	a	5.1	0.4122
Black-seeded plantain	*Plantago rugelii*	0.46	20	0.0	a	0.5	a	0.9	a	5.1	0.1773

Sky blue aster	*Symphyotrichum oolentangiense*	0.42	20	0.2	a	0.3	a	0.8	a	4.3	0.3691
Late horse gentian	*Triosteum perfoliatum*	0.40	8	0.3	a	0.6	a	0.3	a	6.9	0.4497
Giant ragweed	*Ambrosia trifida*	0.40	13	0.8	a	0.1	a	0.2	a	6.1	0.6872
Common mullien	*Verbascum thapsus*	0.35	13	0.0	a	0.4	a	0.7	a	4.2	0.0553
Mayapple	*Podophyllum peltatum*	0.35	4	0.2	a	0.7	a	0.2	a	16.2	0.8493
Virginia ground cherry	*Physalis virginiana*	0.33	11	0.2	a	0.3	a	0.6	a	4.2	0.3415
Honewort	*Cryptotaenia canadensis*	0.32	20	0.6	a	0.2	a	0.1	a	2.8	0.8350
Crown vetch	*Securigera varia*	0.31	1	0.0	a	0.0	a	0.9	a	26.8	0.4096
Tall cinquefoil	*Potentilla arguta*	0.31	18	0.3	a	0.3	a	0.4	a	2.8	0.6048
Robin's plantain	*Erigeron pulchellus*	0.31	18	0.4	a	0.4	a	0.1	a	2.8	0.1457
Indian Hemp	*Apocynum cannabinum*	0.31	8	0.6	a	0.0	a	0.3	a	5.3	0.4694
Grass leaf goldenrod	*Euthamia graminifolia*	0.30	7	0.4	a	0.0	a	0.5	a	4.1	0.6476
American vetch	*Vicia americana*	0.30	12	0.3	a	0.4	a	0.2	a	3.5	0.4894
Bird's foot violet	*Viola pedata*	0.25	12	0.4	a	0.3	a	0.0	a	2.6	0.1755
Old field cinquefoil	*Potentilla simplex*	0.23	10	0.1	a	0.0	a	0.6	a	2.6	0.0840
American cow parsnip	*Heracleum sphondylium ssp montanum*	0.23	1	0.7	a	0.0	a	0.0	a	14.5	0.4096
Rough cinquefoil	*Potentilla norvegica (running)*	0.23	5	0.5	a	0.2	a	0.0	a	3.3	0.3304
Ostrich fern	*Matteuccia struthiopteris*	0.22	4	0.0	a	0.5	a	0.2	a	3.3	0.2254

Wood nettle	*Laportea canadensis*	0.19	6	0.2	a	0.4	a	0.0	a	3.7	0.6433
Purple stemmed aster	*Symphyotrichum puniceum*	0.19	10	0.2	a	0.3	a	0.1	a	1.8	0.6336
Wild carrot	*Daucus carota*	0.18	9	0.3	a	0.0	a	0.2	a	1.8	0.4827
Early buttercup	*Ranunculus fasicularis*	0.18	19	0.1	a	0.3	a	0.1	a	0.4	0.6265
Yellow wood sorrel	*Oxalis stricta*	0.17	18	0.3	a	0.2	a	0.1	a	0.4	0.1736
Golden Alexander	*Zizia aurea*	0.17	3	0.0	a	0.2	a	0.3	a	2.5	0.4080
St John's wort	*Hypericum pyramidatum*	0.16	12	0.1	a	0.3	a	0.2	a	1.1	0.4156
White clover	*Trifolium repens*	0.16	7	0.2	a	0.1	a	0.3	a	1.8	0.5503
Creeping charlie	*Glechoma hederacea*	0.16	2	0.0	a	0.2	a	0.3	a	3.6	0.6243
Wood anemone	*Anemone quinquefolia*	0.15	6	0.4	a	0.0	a	0.1	a	1.7	0.2588
Smooth ground cherry	*Physalis subglabrata*	0.15	11	0.3	a	0.1	a	0.0	a	1.0	0.4573
Fringed loosestrife	*Lysimachia ciliata*	0.14	5	0.2	a	0.2	a	0.0	a	1.7	0.2949
Common milkweed	*Asclepias syriaca*	0.14	5	0.2	a	0.2	a	0.1	a	1.7	0.8236
Prairie buttercup	*Ranunculus rhomboideus*	0.13	9	0.0	a	0.1	a	0.0	a	1.0	0.1448
Wild yam	*Dioscoria villosa*	0.13	4	0.0	a	0.2	a	0.2	a	1.7	0.4096
Culver's root	*Veronicastrum virginicum*	0.13	4	0.1	a	0.0	a	0.3	a	1.7	0.5147
Starry solomon's seal	*Maianthemum stellatum*	0.12	3	0.0	a	0.3	a	0.0	a	1.7	0.5702
Stiff goldenrod	*Solidago rigidum*	0.11	2	0.2	a	0.2	a	0.0	a	1.7	0.6243

Field pussytoes	*Antennaria neglecta*	0.11	2	0.0	a	0.0	a	0.3	a	2.8	0.6253
Pea vine lathyrus	*Lathyrus latifolius*	0.08	4	0.2	a	0.0	a	0.0	a	0.9	0.5240
Hog peanut	*Amphicarpaea bracteata*	0.08	9	0.1	a	0.1	a	0.1	a	0.2	0.7121
Curly dock	*Rumex crispus*	0.08	4	0.0	a	0.0	a	0.2	a	0.9	0.3010
Virginia waterleaf	*Hydrophyllum virginianum*	0.08	4	0.3	a	0.0	a	0.0	a	0.9	0.4096
Yarrow	*Achillea millefolium*	0.07	8	0.0	a	0.1	a	0.1	a	0.2	0.5085
White arrow-leaf aster	*Symphyotrichum urophyllum*	0.07	8	0.0	a	0.0	a	0.2	a	0.2	0.0897
Eastern black nightshade	*Solanum ptycanthum*	0.07	8	0.2	a	0.0	a	0.0	a	0.2	0.0885
Columbine	*Aquilegia canadensis*	0.07	8	0.0	a	0.1	a	0.1	a	0.2	0.4455
Deptford pink	*Dianthus armeria*	0.07	3	0.0	a	0.1	a	0.2	a	0.9	0.5728
Plumeless thistle	*Carduus acanthoides*	0.06	2	0.0	a	0.0	a	0.2	a	0.9	0.6253
Figwort	*Scrophularia marilandica*	0.06	1	0.0	a	0.2	a	0.0	a	0.8	0.4096
Michigan Lily	*Lilium michiganense*	0.06	1	0.0	a	0.2	a	0.0	a	0.8	0.4096
Nodding/Musk thistle	*Carduus nutans*	0.06	1	0.2	a	0.0	a	0.0	a	0.8	0.4096
Japanese hedge parsley	*Torilis japonica*	0.06	1	0.2	a	0.0	a	0.0	a	0.8	0.4096
Orange jewelweed	*Impatiens capensis*	0.05	5	0.1	a	0.0	b	0.0	b	0.1	0.0390
Jack in the pulpit	*Arisaema triphyllum*	0.05	5	0.1	a	0.0	a	0.0	a	0.1	0.6561

Common ragweed	*Ambrosia artemisiifolia*	0.05	5	0.1	a	0.0	a	0.1	a	0.1	0.8208
Lambsquarters	*Chenopodium album*	0.04	4	0.0	a	0.1	a	0.0	a	0.1	0.7843
Spiderwort	*Tradescantia ohiensis*	0.03	3	0.0	a	0.0	a	0.1	a	0.1	0.4096
Pale smartweed	*Persicaria lapathifolia*	0.03	3	0.0	a	0.0	a	0.1	a	0.1	0.4096
Tall thimbleweed	*Anemone virginiana*	0.02	2	0.0	a	0.0	a	0.0	a	0.0	0.6243
Calico aster	*Symphyotrichum lateriflorum*	0.02	2	0.0	a	0.0	a	0.0	a	0.0	0.6243
False Lily-of-the-valley	*Maianthemum canadense*	0.02	2	0.0	a	0.0	a	0.0	a	0.0	0.6253
Upright carrionflower	*Smilax ecirrhata*	0.02	2	0.0	a	0.0	a	0.0	a	0.0	0.6253
Wild onion	*Allium canadense*	0.02	2	0.0	a	0.1	a	0.0	a	0.0	0.1936
Little leaf buttercup	*Ranunculus arborvitus*	0.01	1	0.0	a	0.0	a	0.0	a	0.0	0.4096
Field bindweed	*Convulvulus arvensis*	0.01	1	0.0	a	0.0	a	0.0	a	0.0	0.4096
Yellow coneflower	*Ratibida pinnata*	0.01	1	0.0	a	0.0	a	0.0	a	0.0	0.4096
Black eyed susan	*Rudbeckia hirta*	0.01	1	0.0	a	0.0	a	0.0	a	0.0	0.4096
Goats beard	*Tragopogon dubius*	0.01	1	0.0	a	0.0	a	0.0	a	0.0	0.4096
Water hemp	*Amaranthus rudis*	0.01	1	0.0	a	0.0	a	0.0	a	0.0	0.4096
Shepherd's purse	*Capsella bursa-pastoris*	0.01	1	0.0	a	0.0	a	0.0	a	0.0	0.4096
White sweet clover	*Melilotus alba*	0.00	0	0.0	a	0.0	a	0.0	a	0.0	--
Graminoids											
Kentucky bluegrass	*Poa pratensis*	7.19	91	6.9	a	5.2	a	9.4	a	289.3	0.5076

Virginia wild rye	*Elymus virginicus*	2.17	86	2.5	a	2.1	a	1.9	a	43.9	0.6589
Pennsylvania sedge	*Carex pensylvanica.*	1.56	48	1.9	a	2.2	a	0.6	a	20.2	0.2436
Reed canarygrass	*Phalaris arundinacea*	0.75	13	0.5	a	1.4	a	0.4	a	35.6	0.3316
Fringed brome	*Bromus ciliatus*	0.72	11	0.0	b	1.0	ab	1.2	a	42.9	0.0208
Quackgrass	*Elytrigia repens*	0.19	5	0.2	a	0.2	a	0.2	a	2.5	0.8120
Smooth brome	*Bromus inermis*	0.15	6	0.0	a	0.3	a	0.2	a	1.7	0.4248
Sedge spp, type 3	*Carex* spp.	0.15	6	0.0	a	0.4	a	0.0	a	1.7	0.0808
Timothy	*Phleum pratense*	0.14	5	0.0	a	0.3	a	0.2	a	1.7	0.1297
Orchardgrass	*Dactylis glomerata*	0.13	4	0.2	a	0.0	a	0.2	a	1.7	0.7836
Tall fescue	*Festuca arundinacea*	0.06	7	0.1	a	0.1	a	0.1	a	0.2	0.8646
Indiangrass	*Sorghastrum nutans*	0.06	1	0.0	a	0.2	a	0.0	a	0.8	0.4069
Big bluestem	*Andropogon gerardii*	0.06	1	0.0	a	0.2	a	0.0	a	0.8	0.4069
Grass	*Poa* spp.	0.06	1	0.0	a	0.0	a	0.2	a	0.8	0.4096
Panicum	*Panicum* spp.	0.01	1	0.0	a	0.0	a	0.0	a	0.0	0.4069
Woody species, cover at quadrats											
American basswood	*Tilia americana*	10.06	85	12.1	a	11.4	a	6.7	a	523.6	0.3366
Slippery elm	*Ulmus rubra*	8.96	106	8.3	a	10.5	a	8.1	a	303.3	0.3052
Bur oak	*Quercus macrocarpa*	7.54	55	5.5	a	10.1	a	7.0	a	466.2	0.2480
Black raspberry	*Rubus occidentalis*	7.44	153	10.0	a	8.4	a	4.0	b	101.3	0.0173
VA creeper	*Parthenocissus quinquefolia*	7.24	138	5.8	a	8.3	a	7.7	a	132.5	0.1170
Grey dogwood	*Cornus racemosa*	6.34	80	3.8	a	8.9	a	6.3	a	238.1	0.0721

Common prickly ash	*Zanthoxylum americanum*	4.63	88	4.1	a	3.5	a	6.3	a	144.1	0.6012
Missouri gooseberry	*Ribes missouriense*	4.47	91	3.9	a	3.8	a	5.7	a	83.7	0.3569
River bank grape	*Vitis riparia Michx*	3.76	91	3.8	a	4.5	a	3.0	a	48.0	0.3260
Wild black cherry	*Prunus serotina*	3.73	36	5.6	a	3.2	a	2.4	a	202.4	0.4067
Honeyscukle	*Lonicera spp.*	3.06	51	2.4	a	2.7	a	4.1	a	98.0	0.9972
Poison ivy	*Toxicodendron radicans*	2.96	32	1.3	a	3.6	a	4.0	a	120.8	0.4512
Red raspberry	*Rubus idaeus*	2.93	58	3.8	a	2.7	a	2.3	a	56.3	0.5645
Eastern black walnut	*Juglans nigra*	2.68	19	3.0	a	2.2	a	2.8	a	170.5	0.6805
American hazelnut	*Corylus americana*	2.53	33	1.8	a	4.1	a	1.8	a	89.6	0.6926
Quaking aspen	*Populus tremuloides*	2.34	34	1.9	a	2.3	a	2.8	a	100.4	0.8184
Chokecherry	*Prunus virginiana*	2.33	40	1.9	a	2.7	a	2.3	a	65.4	0.8864
Blackberry	*Rubus allegheniensis*	2.33	62	2.2	a	2.6	a	2.2	a	28.9	0.8733
Shagbark hickory	*Carya ovata*	1.66	26	2.0	a	1.9	a	1.1	a	50.1	0.9413
Butternut	*Juglans cinerea*	1.31	8	0.0	a	2.0	a	1.9	a	99.4	0.1842
Smooth sumac	*Rhus glabra*	1.27	32	1.6	a	1.4	a	0.8	a	22.1	0.4726
Nannyberry	*Viburnum lentago*	1.08	15	0.7	a	2.1	a	0.4	a	48.4	0.4256
American plum	*Prunus americana*	1.03	26	1.1	a	0.4	a	1.6	a	17.9	0.3189
Hawthorn	*Crataegus spp.*	0.94	26	1.4	a	1.0	a	0.4	a	14.0	0.4493
Downy arrowwood	*Viburnum rafinesqueanum*	0.84	16	0.4	a	1.3	a	0.8	a	15.4	0.5550
Elderberry	*Sambucus canadensis*	0.57	4	1.7	a	0.0	a	0.0	a	32.5	0.4096
Boxelder	*Acer negundo*	0.53	9	1.0	a	0.5	a	0.1	a	29.4	0.8088
Black oak	*Quercus velutina*	0.48	4	0.0	a	0.0	a	1.4	a	28.6	0.8082

American elm	*Ulmus americana*	0.42	2	0.0	a	0.0	a	1.3	a	29.3	0.4096
Autumn olive	*Elaeagnus umbellata*	0.42	10	0.4	a	0.2	a	0.6	a	8.1	0.9186
Multiflora rose	*Rosa multiflora*	0.33	6	0.5	a	0.2	a	0.3	a	6.1	0.9999
Wild rose	*Rosa spp.*	0.32	15	0.0	a	0.4	a	0.6	a	3.5	0.1056
Summer grape	*Vitis aestivalis*	0.13	4	0.1	a	0.3	a	0.0	a	2.9	0.4096
Willow	*Salix spp.*	0.11	2	0.0	a	0.3	a	0.0	a	2.8	0.1946
Apple	*Malus spp.*	0.06	2	0.0	a	0.0	a	0.2	a	0.9	0.1946
Mulberry	*Morus spp.*	0.06	1	0.2	a	0.0	a	0.0	a	0.8	0.4096
Hophornbeam	*Ostrya virginiana*	0.06	1	0.2	a	0.0	a	0.0	a	0.8	0.4096
Northern red oak	*Quercus rubra*	0.05	5	0.0	a	0.1	a	0.1	a	0.1	0.8200
Native honeysuckle	*Lonicera dioica L.*	0.02	2	0.1	a	0.0	a	0.0	a	0.0	0.4096
Staghorn sumac	*Rhus typhina*	0.01	1	0.0	a	0.0	a	0.0	a	0.0	0.4096
Clematis vine	*Clematis spp.*	0.01	1	0.0	a	0.0	a	0.0	a	0.0	0.4096
Sugar Maple	*Acer saccharum Marsh.*	0.00	0	--	--	--	--	--	--	0.0	1.0000
Hackberry	*Celtis occidentalis*	0.00	0	--	--	--	--	--	--	0.0	1.0000
Red osier dogwood	*Cornus sericea*	0.00	0	--	--	--	--	--	--	0.0	1.0000
Common buckthorn	*Rhamnus cathartica*	0.00	0	--	--	--	--	--	--	0.0	1.0000
Lady fern	*Athyrium filix-femina*	0.00	0	--	--	--	--	--	--	0.0	1.0000
Cranberry viburnum	*Viburnum trilobum*	0.00	0	--	--	--	--	--	--	0.0	1.0000
Ash	*Fraxinus spp*	0.00	0	--	--	--	--	--	--	0.0	1.0000

[1] Mixed model means and (±SE) associated with comparison of treatment main-effects means.

[2] Mixed model ranked *P* value associated with treatment *F-test*.

[3] Percent cover per 1 square meter from 270 quadrats

Table 11. Goat kid average daily gain (g) by research location over 2011 to 2013.

Location[3]	LSMeans	SE	n[2]	DF	*t* Value	*P* Value[1]	Letter Group
YLWA	114.40	3.22	114	428	35.54	<.0001	a
OK	104.74	3.11	122	428	33.66	<.0001	a
MD	49.69	2.46	195	428	20.19	<.0001	b

[1] Mixed model *P* value associated with gain *F*-test.

[2] Sample size for each location by year combination

[3] YLWA is in Wisconsin, OK is Oklahoma, and MD is Maryland.

Table 12. Goat kid average daily gain (g) by research year, averaged over 3 locations.

Year	LSMeans	SE	n[2]	DF	*t* Value	*P* Value[1]	Letter Group
2012	95.85	3.73	138	428	25.72	<.0001	a
2011	86.12	3.48	158	428	24.73	<.0001	a
2013	64.25	3.77	135	428	17.05	<.0001	b

[1] Mixed model *P* value associated with gain *F*-test.

[2] Sample size for each year.

Table 13. Goat kid average daily gain (g) by research location and year.

Location and Year[3]	LSMeans	SE	n[2]	DF	*t* Value	*P* Value[1]	Letter Group
YLWA 2012	143.22	5.09	34	422	28.15	<.0001	a
OK 2013	128.28	5.93	25	422	21.62	<.0001	a
YLWA 2011	125.71	4.69	40	422	26.8	<.0001	a
OK 2011	103.31	4.69	40	422	22.02	<.0001	b
OK 2012	95.41	3.93	57	422	24.28	<.0001	bc
YLWA 2013	78.58	4.69	40	422	16.75	<.0001	cd
MD 2012	62.11	4.33	47	422	14.35	<.0001	de
MD 2011	57.00	3.36	78	422	16.97	<.0001	e
MD 2013	33.19	3.55	70	422	9.36	<.0001	f

[1] Mixed model *P* value associated with gain *F*-test.

[2] Sample size for each location by year combination

[3] YLWA is in Wisconsin, OK is Oklahoma, and MD is Maryland.

APPENDIX C:

Seed Mix

Grasses Interseeded

Species	**Common Name**	**Seed by Weight (lbs)**
Andropogon gerardii	Big Bluestem	10.0
Bouteloua curtipendula	Side Oats Grama	10.0
Elymus canadensis	Canada Wild Rye	10.0
Panicum virgatum	Switchgrass	10.0
Schizachyrium scoparius	Little Bluestem	10.0
Sorghastrum nutans	Indiangrass	10.0
Total		**60.0**
Rate		**8.0 lbs/hectare**

Forbs Interseeded

Species	**Common Name**	**Seed by Weight (lbs)**
Amorpha canascens	Lead Plant	1.5
Symphyotrichum oolentangiensis	Sky Blue Aster	1.5
Astragalus canadensis	Canadian Milk Vetch	1.0
Baptisia alba	Wild White Indigo	0.5
Baptisia bracteata	Cream False Indigo	1.5
Ceanothus americanus	New Jersey Tea	2.0
Chamaecrista fasciculata	Partridge Pea	1.0
Dalea purpurea	Purple Prairie Clover	0.5
Desmodium canadense	Showy Tick Trefoil	0.5
Echinacea pallida	Pale Purple Coneflower	0.9
Heliopsis helianthoides	Oxeye Sunflower	1.5
Lespedeza leptostachya	Prairie Bush Clover	1.5
Liatris pycnostachya	Prairie Blazing Star	0.5
Monarda fistulosa	Bergamot	1.5
Parthenium integrifolium	Wild Quinine	0.5
Potentilla arguta	Prairie Cinquefoil	0.5
Ratibida pinnata	Yellow Coneflower	1.5
Rudbeckia hirta	Black-Eyed Susan	0.5
Solidago rigida	Stiff Goldenrod	0.5
Silphium integrifolium	Rosinweed	0.5
Veronicastrum virginicum	Culver's Root	1.5
Zizia aurea	Golden Alexander	1.5
Total		**21.4**
Rate		**2.9 lbs/hectare**

Total Seeding Rate = 10.9 lbs/hectare

APPENDIX D:

Goat Production Costs

Table 1. Goat budget for C. Nolden goat herd

250	Does
90	Average weight does (lbs)
2.10%	% of BW in DMI daily
180	Days of stored forage feeding
340.2	Pounds of DM hay per doe/yr
$1,000.00	Mineral/yr for herd
$4.00	Mineral cost per head/yr
$150.00	$/ton DM ($1/RFQ point) winter forage
$0.08	$/lb DM
$25.52	$ in stored forage/doe/yr consumed
20%	% of forage DM wasted by does
$5.10	$/doe of wasted forage
$34.62	Cost per doe per year (baleage and mineral)
1.5	Kidding rate (kids/doe)
375	Kids/year produced
5%	% doe replacement
12.5	Doelings retained annually
5%	% kid loss per year
18.75	Kids lost per year
343.75	Kids for sale at Christmas auction
90	Days of kids on forage (Oct, Nov, Dec)
48	Average kid weight during feeding, lbs
3.50%	% of BW in DMI daily
577.5	Pounds of DM/day eaten by sale kids
26	Tons DM needed to feed kids
20%	% of forage DM wasted by kids
5.2	Tons of DM wasted by kids
$4,677.75	Cost of kid forage up to auction time
57	Average kid weight at auction, lbs
$2.60	$/lb paid for kids at auction
$148.20	$ per kid at auction
$80.00	$/cull doe at auction
$46,266.00	Kid income if all sold for above price
$1,000.00	Cull doe income
$8,654.50	Cost of feeding doe herd
$38,611.50	Difference (income)

Table 1 is a tabulation of expenses and income for management of Cherrie Nolden's meat goat herd and is reflective of what similar forage-based goat herds could expect to spend and collect in this kind of goat management system. A herd of 250 does that average 90 lbs in mature weight, and consume 2.1% of their body weight in dry matter per day over the 180 days that they are maintained on stored forages will consume 340.2 lbs of forage dry matter per doe per year. The reminder of the year the does are consuming brush as their forage and not supplemented with stored forages or grain. Mineral consumed free-choice by Cherrie's herd is available year-round, and the does and kids consume $1000.00 worth of mineral annually, which comes out to $4.00 per doe per year. Purchasing winter forage for the doe herd at $1.00 per RFQ (relative forage quality) point per ton, with a target RFQ of $150.00 per ton of dry matter results in a cost of $0.08 per pound of dry matter fed to the does. Since the herd eats 340.2 lbs of dry matter per doe, each doe costs $25.52 in consumed forage to feed over winter. Since goats are very picky with their forage, there is always wasted forage in a goat production system. Twenty percent wasted forage is what Cherrie figures is appropriate with the sliding Ketcham feeder panels, which equates to an additional $5.10 per doe per year of forage costs. Total forage and mineral costs per doe per year is $34.62.

If the does produce a conservative 1.5 kids per year, this would result in 375 kids produced by the 250 does. Retaining 5% of those as doe replacements, and planning for a 5% death loss of kids annually results in 343.75 kids for sale at the time of year when market prices are reliably high, the Christmas market. Since natural forage is consumed from April 15 to October 15, goat kids for market will need to be fed stored forages between October 15 and

Christmas, or approximately 90 days each year. The kids average 48 lbs over that 90 day period, and are ready for market at 57 lbs. The kids consume 3.5% of their body weight in forage dry matter daily over this period, which amounts to 26 tons of dry matter consumed. They are also wasteful with forage and Cherrie adds 20%, or 5.2 tons, of dry matter to the amount consumed as goat kid costs. The total cost of kid forage fed from October 15 to Christmas auction time is $4,677.75. If goat kids sell for the mix-bred price on the auction ticket in Chapter 1 Figure 4, of $2.60 per pound live weight, and they average 57 pounds, each kid will be worth $148.20. The 5% of does culled would likely bring around $80.00 per goat at auction. The total income from goat kids under the above assumptions would be $46,266.00. Cull doe income would be $1,000.00. The costs for feeding the doe herd over winter is a maintenance cost that counts against the income from the goat kids and cull does, and is $8,654.50. The net income then, under the above assumptions, for the goat herd is $38.611.50 annually.

These costs are not a full accounting of all anticipated expenses of running a goat operation, but are reflective of realistic feed and mineral costs of this approach to management. Other items needed for managing goats in brush include portable electrified netting fences (~40 fences for a herd of 250 does), energizers, deep charge marine batteries, battery rechargers or solar panels, ground rods, fence tester, battery tester, water and mineral containers, a trailer and truck, a guardian animal, and a chainsaw with fuel and oil. Labor for clearing fence lanes, maintaining the lanes, checking fences, filling water and mineral, checking goats, setting up and taking down fences, and responding to incidents such as escapes is a significant aspect of this management approach also. Maintaining the does over winter requires low-cost 3-sided shelter with bedding, water and mineral containers, pen panels that hold up to snow and ice load, and feeder panels that reduce forage waste. Cherrie developed and tested a portable goat shelter design, with results available in the SARE database (Nolden, 2014; Nolden, 2015), showing that goats will use as little as 5.7 square feet of shelter space effectively (19.5 goats per 112 square feet), despite the Animal Welfare Approved recommendation of 16 square feet per adult goat (A Greener World, 2019).