ANALYZING SERICEA LESPEDEZA (*LESPEDEZA CUNEATA*) MANAGEMENT PRACTICES AND THE IMPORTANCE OF FORBS IN THE DIET OF CATTLE AND BISON ON TALLGRASS PRAIRIE

By

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Abstract: Managing an invasive species while simultaneously preserving native plant diversity can be a challenge and species invasions are best understood when they are studied at multiple spatiotemporal scales. Using two large, tallgrass prairie landscapes managed to promote diversity; we assessed sericea lespedeza (*Lespedeza cuneata*) management practices and the effects that management had on the native plant community. At one study area, an experimental approach was taken to determine the long-term effects (19 years) of pyric herbivory on sericea lespedeza invasion and at the other study area, we performed a 21-year observational study on the effects of pyric herbivory and herbicide applications on sericea lespedeza. We also assessed the importance of forbs and an invasive legume in the diet of cattle and bison on tallgrass prairie using the *trn*L meta-barcoding technique. Our results indicate that the restoration of pyric herbivory with bison or cattle continues to provide the greatest invasion mitigation for sericea when compared to traditional management methods at landscape scales. Sericea invasion, as well as the management strategies put in place to control sericea, has minimal impact on the native plant community. Conservatively applied herbicide applications appeared to provide only one year of sericea control and there was no evidence for long-term benefits. Assuming that the relative read abundance (RRA) percentage for a species corresponds to the percentage of protein derived from that species; our results indicate that dicots provided 70-80% of the dietary protein throughout the growing season in both cattle and bison. Forbs in the legume family provided 60-65% of protein intake for both cattle and bison. Lespedeza sp., likely sericea, provided an average of 25-30% of bison and cattle protein intake throughout the growing season.

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AN ECOLOGICAL PROCESS PROVIDES INVASION MITIGATION; CAN HERBICIDE APPLICATIONS BE ADDITIVE?

ABSTRACT

Managing an invasive species while simultaneously preserving native plant diversity can be a challenge and species invasions are best understood when they are studied at multiple spatiotemporal scales. Using two large, tallgrass prairie landscapes managed to promote diversity; we assessed sericea lespedeza (*Lespedeza cuneata*) management practices and the effects that management had on the native plant community. At one study area, an experimental approach was taken to determine the long-term effects (19 years) of pyric herbivory on sericea lespedeza invasion and at the other study area, we performed a 21-year observational study on the effects of pyric herbivory and herbicide applications on sericea lespedeza. Our results indicate that the restoration of pyric herbivory with cattle or bison continues to provide the greatest invasion mitigation for sericea when compared to traditional management methods at landscape

scales. We found that sericea invasion, as well as the management strategies put in place to control sericea, had minimal impact on the native plant community. Conservatively applied herbicide applications appeared to provide only one year of sericea control and there was no evidence for long-term benefits. Varying the seasonality of fire to include growing season fire did not appear to inhibit sericea invasion long-term.

INTRODUCTION

Invasive species are one of the leading causes of biodiversity decline in native plant communities throughout all biomes of the world (Didham et al., 2005; Pimental et al., 2005; Wilcove et al., 1998) second only to habitat destruction (Pimm and Gilpin 1989; Randall 1996). Invasive species invasions have been shown to have negative impacts on many ecosystem services (Mooney 2005; Pejchar and Mooney 2009) including some that are directly and indirectly important to humans (Pejchar and Mooney 2009; Jones, 2017). Invasive species are estimated to cost the United States in excess of 120 billion dollars annually (Pimental et al., 2005) but for many species, there is a lack of data on control and damage cost, which implies that the true cost is likely much higher than current estimates (Pimentel et al. 2005; Bradshaw et al. 2016). Invasive species pose significant threats to the economies and ecosystems of the United States and beyond (NISC 2016) and with expanding distributions and increasing dominance, they are a concern to ecologists, conservationists and landowners (Brandon et al., 2004; Coblentz 1990; Meiners et al., 2002).

Species invasions are best understood when they are studied at multiple spatiotemporal scales (Fuhlendorf et al. 2012). Traditional invasive plant control research typically involves short term research (≤ 2 years) applying control methods to small (≤ 30 m^2) plots with sampling plots being ≤ 1 m^2 (Kettering and Adams, 2011). Ecological processes and patterns are highly variable at multiple scales and studies of the relationship between invasive species and native species diversity often indicate negative relationships at small scales and positive relationships at large scales (Fridley et al. 2007). These opposing patterns found in this “invasion paradox” (Fridley et al. 2007) are partially the result of capturing different ecological processes operating at differing spatial scales (Levine and D’Antonio 1999; Stohlgren et al. 1999; Levine 2000; Shea and Chesson 2002). The relationship between diversity and disturbance relates to invasions because by widening niche space associated with disturbances or the temporary reduction in dominance of certain species, invasive species can capitalize on the reduced competition (Elton, 1958; Tilman, 1997; Gurvich et al. 2005). In rangelands, the processes that create and maintain species diversity can also contribute to that areas invasibility (Fuhlendorf et al. 2012).

The use of ecologically based invasive plant management (EBIPM) (Sheley et al., 2006; Krueger-Mangold et al., 2006; Sheley and Smith 2012) and “usable science” (Usable Science 2010; Mackzo et al. 2016) is a growing focus in understanding and managing for invasive species. EBIPM focuses on the underlying ecological cause on invasions and that sustainable management of invasive species should focus on restoring diverse plant communities (Sheley et al., 2006; Krueger-Mangold et al., 2006; Shelly and Smith 2012). An approach based on EBIPM would also be associated with a “usable science” approach that incorporates the end users (i.e. land managers/owners, state/federal agency personnel, policy makers, non-governmental organizations, etc.) throughout the entire scientific process in order to create a more usable product. Usable science involves conducting research at much larger scales than has been the norm but is capable of addressing multiple land use objectives and is highly representative of the commercial scale (Fuhlendorf and Brown 2016).

Our focus for this study is on sericea lespedeza (*Lespedeza cuneata* [Dum.-Cours] G. Don), hereafter referred to as sericea, which is an introduced perennial legume that was brought into the United States from eastern Asia in 1896 by the United States Department of Agriculture (USDA) (Cummings et al. 2007). The success of this species is largely due to its high fecundity, wide tolerance to different soil pH values, low palatability during the late growing season, a high total leaf area, and the ability out compete natives for sunlight (Stitt and Clarke 1941; Donnelly 1954; Brandon et al. 2004; Allred et al. 2010). While in its early growth stages, sericea is highly palatable and nutritious for cattle but as the plant matures, digestibility decreases (Clarke et al. 1939; Stitt and Clark 1941; Donnelly 1954) because of the production of phenolic tannins, which become increasingly concentrated as the plant ages (Mosjidis et al. 1990). Tannins bind proteins within the plant, leaving them unavailable to most ruminants during digestive processes (Min et al., 2003). Tannins have the ability to cause negative post-ingestive effects in herbivores such as stomach discomfort (gastrointestinal malaise) and a loss of appetite (Provenza et al. 1990; Silanikove et al. 2003). In the tallgrass prairie of Kansas and Oklahoma, the invasion of sericea is thought to poses a threat to biotic integrity and traditional land use objectives, i.e. livestock production, (Eddy and Moore, 1998).

Historically, control efforts for sericea have focused largely on the use of selective herbicides; however, the use of fire to alter grazing preferences and targeted grazing has been demonstrated to be more effective in some cases (Cummings et al. 2007). Pyric herbivory, grazing driven by fire, is an ecological process that was important to the development and maintenance of pre-European grasslands of North America (Fuhlendorf et al. 2009). Patch burning is a management approach that applies the ecological process of pyric herbivory to restore heterogeneity in a grazing management scenario. (Fuhlendorf and Engle 2001, 2004; Fuhlendorf et al. 2009). Pyric herbivory is a more effective management approach for sericea when compared to the traditional rangeland management approach at moderate spatial (mean experimental unit = 64 ha), and temporal scales (6 years) (Cummings et al. 2007). Seasonality of fire has been proposed to have an effect on sericea lespedeza invasion and some studies have made conservative claims that growing season fire reduces invasion rates (Cummings et al. 2007), and seedling survivorship (Wong et al. 2012). Selective herbicides such as metsulfuron-methyl (methyl 2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]benzoate), triclopyr ([(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid), have provided some control of sericea (Altom & Stritzke 1992; Koger et al., 2002) but not efficient control (Cummings et al., 2007). As a highly fecund species sericea is capable of creating a seed bank in the soil with enough viable seeds to provide new sericea plants for many years post application although research to determine the exact longevity of the seeds is minimal (Stitt and Clarke 1941; Donnelly

1954). Many of the common chemicals used in sericea control are broadleaf herbicides, designed to kill or suppress forbs (Crone et al., 2009). While repeated herbicidal application is rather costly, there is also evidence that it can have negative effects on native forb composition in native rangeland settings (Koger et al., 2002) and may even exacerbate invasive species problems (Rinella et al. 2009).

We had the unique opportunity of using two long-term data sets at large spatial scales on two separate study sites in order to evaluate sericea lespedeza dynamics on tallgrass prairie landscapes. Both landscapes include treatments that are designed to be spatially and temporally variable. One site is a controlled experiment with 131 fires while the other is a large landscape, ~16,000 ha with 541 fires and 44,980 ha of herbicide applications dispersed across a working landscape, resulting in an opportunity to combine controlled experiments with large-scale observations. Sericea lespedeza is a widespread invasive species throughout the tallgrass prairie of Oklahoma and Kansas and warrants large-scale and long-term research on possible control methods and their effects to the native plant community. Using these separate long-term data sets from an experimental and observational study along a usable science approach, the objectives of our study were to:

1) Determine if pyric herbivory is a viable sericea invasion mitigation method.
2) Determine the effect of fire seasonality on sericea invasion.
3) Evaluate the effect that sericea presence and abundance has on the native plant community.
4) Evaluate the effects that sericea control efforts has on the native plant community.

5) Determine if the large-scale application of herbicides is a viable sericea invasion mitigation method.

MATERIALS AND METHODS

Study Areas

Our first study location is the Oklahoma State University Range Research Station (OSURRS) in Payne County, located approximately 21 kilometers southwest of the city of Stillwater, Oklahoma. The research station is located along the edge of the tallgrass prairie and the cross-timbers ecoregion and is 2,020 hectares. The OSURRS is the site of a controlled experiment testing pyric herbivory and traditional management (Fuhlendorf and Engle 2004; Cummings et al., 2007). The pyric herbivory treatment pastures (n=3) consist of six distinct patches within each pasture, with one patch being burned in the spring (dormant season) of each year and one patch being burned in the summer (growing season) of each year (Figure 1). The traditional management approach involves the spring (dormant season) burning of entire pastures, every third year. All dormant season fire occurred in the months of February-April and growing season fire occurred in July-October with 71.4% occurring in July and August (Table 1). Sericea lespedeza is present and previous work demonstrated it was invading the area at a rate of 2% vegetative cover per year, depending on which fire/grazing management strategies are implemented (Cummings et al. 2007).

Our second study location is at The Nature Conservancy's Tallgrass Prairie Preserve (TGP) in Osage County, Oklahoma, approximately 21 kilometers north-

northwest of the city of Pawhuska, Oklahoma. The 16,000-hectare TGP is located within the southern extent of the Flint Hills ecoregion of the Great Plains along the edge of the cross-timbers ecoregion and is part of the largest intact portion of the tallgrass prairie in North America. The TGP uses prescribed fire that varies both spatially and temporally in order to recouple the fire and grazing interaction. At the TGP, pyric herbivory is done in a less systematic manner than at the OSURRS. There are multiple patches of differing sizes across the entire landscape. These patches are burned on a random basis, with the goal of maintaining a ~ 3-year mean fire return interval across the landscape (Hamilton 2007). At the TGP, 89.5% of dormant season fire occurs in March and April while 71.6% of growing season fire occurs in August and September (Table 1). Sericea lespedeza has invaded the TGP, but to an unknown extent. In attempts to control sericea while also limiting non-target damage to native forbs, the TGP have been applying several different herbicides with various means of application (Spot Spray = applied via ATV mounted sprayer; Broadcast = applied via truck with broadcast nozzles; Aerial = applied via aircraft) since 1996.

Both of our study sites consist of 80-90 percent tallgrass prairie and 10-20 percent oak woodland/crosstimbers. Dominant grasses at both study sites include big bluestem (*Andropogon gerardii* Vitman), little bluestem (*Schizachyrium scoparium* [Michx.] Nash), Indian grass (*Sorghastrum nutans* [L.] Nash), switchgrass (*Panicum virgatum* L.), composite dropseed (*Sporobolus compositus* [Poir.] Merr.), blue grama (*Bouteloua gracilis* [Kunth] Lag. Ex Griffiths) and sideoats grama (*Bouteloua curtipendula* [Michx.] Torr.). Dominant forbs include iron weed (*Veronia* spp.), milkweed (*Asclepias* spp.), western ragweed (*Ambrosia psilostachya* DC.), common broomweed *(Gutierrezia* *dracunculoides* [DC.] S.F. Blake) and ashy sunflower (*Helianthus mollis* Lam.). Post oak (*Quercus stellata* Wangenh.), blackjack oak (*Quercus marilandica* Münchh) and hackberry (*Celtis* spp.) dominate the crosstimbers/oak woodland areas of our study sites. The OSURRS and the TGP both experience hot summers (average summer high temperature 2003-2017 = ~32°C) and cold winters (average winter low temperatures 2003-2017 = ~ 2.8°C). Average annual rainfall at the OSURRS and the TGP is 871 mm and 960 mm, respectively. We obtained weather data form the Oklahoma Mesonet (http://www.mesonet.org/) using the Marena (OSURRS) and Foraker (TGP) towers located on our study sites.

Data Collection

Oklahoma State University Range Research Station

At the OSURRS, data collection procedures closely follow those outlined in (Cummings et al. 2007) with six individual pastures (0.8 x 0.8 km) having been subject to one of two treatments since 1999. Those treatments were: 1) pyric herbivory and 2) the traditional management for rangelands in the area. The only difference between treatments is the timing and pattern of the burns, as for every three years, each treatment type will have had approximately the same number of acres burned. From 1999 to 2005 each treatment was subject to grazing at a stocking rate of .83 ha per AUM (AUM = animal unit month) by crossbred stocker cattle. From 2006 to 2018, each treatment type has been grazed year round at a similar stocking rate by Angus bred cow-calf pairs. Cattle in both treatment types, had continuous access to the entire pasture. We collected vegetation metrics in July-August 2017 and July-August 2018 using random subsampling with 30, 0.1 m^2 quadrats per patch, totaling 180 subsamples per pasture, per year. We visually estimated vegetation cover and assigned a cover class (Daubenmire, 1959) to each of the following categories: sericea, other legumes, tallgrass, little bluestem, other perennial grasses, annual grasses and forbs. No samples were collected within 20-meters of all fence lines, roads, pipeline right-of-ways, and closed canopy crosstimbers/eastern red cedar.

Joseph H. Williams Tallgrass Prairie Preserve

At the TGP, we resampled vegetation at permanent 100 m^2 vegetation-monitoring plots established from 1997-2000, located at the intersections of the 1 km x 1 km UTM grid across the TGP. Of the 151 UTM grid plots (Palmer et al. 2003; Palmer 2007; McGlinn et al., 2010), 122 were relocated and sampled in June of 2017 and 2018 (Figure 2). The corner of each plot was marked with a reinforcement bar driven flush to the soil surface and topped with a Surv-Kap® aluminum cap, stamped with the plot ID number. In order to re-locate plots, we used a Trimble® Juno® 3B GPS receiver and a CST/berger® Magna-Trak 100® magnetic locator. At each plot we visually estimated canopy cover percentage and assigned a percent cover (See Appendix A), analogous to the cover classes outlined in (McGlinn et al., 2010), for the following variables: grass, forb, litter, bare ground, rock, sericea and for a selected group of forbs (See Appendix B) at the 100 m^2 scale. The selected group of forbs consisted of forbs important for conservation and those most expected to be sensitive to herbicide treatments. The original sampling of these plots occurred between the years of 1997-2000 and data from the original sampling is used as the "historic" data. These data are accessible via Ecological Archives at: (http://esapubs.org/archive/ecol/E091/124/). We created a long-term management history for each plot using ArcMap 10.4 and shape files from TGP personnel. Management related variables included herbicide applications and prescribed fire applications. Seasonality of prescribed fire was broken into two broad categories, growing season and dormant season, with growing season fires being any that occurred from May 1 through October 31. In terms of time since herbicide (months), we assigned plots that have did not receive a herbicide application during the 21 year study period a value of 276 (2017 samples) and 288 (2018 samples), which signify the number of months elapsed since The Nature Conservancy purchased the property.

Statistical Analyses

For vegetation data collected at both study sites, we used the midpoint values for each cover class and performed an arcsin(square root) transformation to all percentage data prior to analyses. When "current" sericea canopy cover is reported, 2017 and 2018 data are combined to create a "current" value and to allow for year-to-year variation. To determine the effect that sericea presence and abundance has on the native plant community at the TGP, we performed regression analyses on non arcsin(square root) transformed data and removed plots containing no sericea from analyses. In order to determine the effects of management (fire/grazing and herbicide) on sericea and the native plant community, we used generalized linear models. Response variables and the models applied to them are found in Table 1. We performed all statistical analyses within the program, R (R Core Team, 2016). We used an information theoretic approach for model selection using the Akaike Information Criterion corrected for small sample size (AICc) and utilized the AICctab function using the bbmle package (Bolker and R Development Core Team, 2017) within R. Models with a ΔAIC score of 2 or less where considered competitive. For models that contained the null model within the ΔAIC score of 2 or less, we considered the null model to be most competitive. Along with AIC, we also used an analysis of variance (ANOVA) to test each model for significance against the null model ($\alpha = 0.05$). For means separations at both sites, we used the Kruskal-Wallis rank sum test ($\alpha = 0.05$) and the Dunn's multiple comparison test ($\alpha = 0.05$) using the FSA package (Ogle et al. 2018) within R.

RESULTS

Oklahoma State University Range Research Station

At the OSURRS, fire/grazing treatments have been consistently applied over the past 19 years and indicate a strong divergence in sericea cover (Figure 3). Pre-treatment data indicate no statistical difference in sericea canopy cover across treatments and after 19 years there is a significant difference in treatment ($P<0.001$) with the patch-burn and traditionally managed pastures having 8.3% and 19.2% sericea canopy cover, respectively (Figure 4). Current cover of sericea for both treatments varied little from measurements taken 12 years ago and sericea canopy cover remains substantially lower in the pyric herbivory treatment. Season of fire had no effect on sericea canopy cover. Sericea lespedeza canopy cover in the dormant and growing season fire patches within the patch-burn treatment pastures at OSURRS, show similar invasion patterns after 19 years of a controlled experiment, where dormant and growing season fire has been applied to the same patch every third year (Figure 5).

Joseph H. Williams Tallgrass Prairie Preserve

Sericea canopy cover at the TGP has significantly increased from near zero historically to 8.8% currently ($P<0.001$). At the initiation of the study, there was minimal invasion by sericea, as 15 of the 122 permanent vegetation-monitoring plots where found to contain sericea, all of which contained less than 1% canopy cover. Currently, sericea is found in 87 of the 122 permanent vegetation monitoring plots with canopy cover percentages ranging from 0.1 – 87.5%. During the 21-year observational study at the TGP, sericea has become a dominant plant across the landscape, with invasion ranging from complete dominance to absence in specific plots (Figure 6). We found no statistical difference in sericea canopy cover in the bison and cattle grazed portions of the landscape. Further, we found no difference in sericea canopy cover with varying amounts of growing season fire (Figure 7). Additionally, we found minimal impacts on the native plant community due to sericea invasion with sericea abundance having a slight negative effect on grass cover ($P=0.04$; $R^2=0.0294$) and a positive effect on forb canopy cover (P=<0.001; R^2=.2158) (Figure 8). Sericea had no impact on the richness or canopy cover of the group of selected forbs (R^2=<.0001).

Generalized linear models used to determine the effect that sericea lespedeza management has on sericea and the native plant community indicate that none of our models adequately predicts the variation in sericea lespedeza cover across the TGP and that management has maintained the native plant community, rather that greatly modifying it. (Table 2) (Appendix C). We found that herbicide applications only decrease sericea canopy cover for 1-year post application (Figure 9). In plots that received a herbicide application in 2016 and those in 2017, we see significant decreases in sericea canopy cover one year post application ($P \leq 0.05$) and a significant increase in sericea canopy cover two years post application ($P \leq 0.05$) (Figure 10). The additive model of time since spray (TSS) and time since fire (TSF) best explains total grass cover yet estimator values indicate that TSS and TSF are only having minimal impacts on total grass cover. Time since fire best explains percent bare ground cover. The total number of herbicide applications has a slight positive influence on forb richness and the canopy cover of plants in the Fabaceae family, within our group of selected forbs. The canopy cover of plants in the Asteraceae family slightly increased as the number of growing season burns increased.

DISCUSSION

Managing invasive species remains a challenge in natural resource management, especially when this goal is combined with maintaining diversity and abundance of native plant species. We demonstrate with an experimental and a large-scale observational study that pyric herbivory is the best management approach for sericea lespedeza control and management with herbicide is minimally additive. Following 19 years of experimental research at the OSURRS and 21 years of observational research at the TGP, we found no difference in sericea canopy cover between the pyric herbivory treatment pastures at the OSURRS and the sericea canopy cover of the TGP, where pyric herbivory occurs across the entire property along with extensive herbicide use. Herbicide reduced cover of sericea for only one year, followed by complete recovery. Additionally, data from both sites indicate that altering season of fire did not increase sericea control efforts.

An important concern with invasive species management is the impact that the invader will have on the abundance and diversity of native plants (Randall 1996). At the landscape level, we found that presence and abundance of sericea lespedeza has little to no negative effects on the native plant community of the TGP (Figure 8). While we found a significant effect of sericea canopy cover on grass canopy cover, the line of fit indicates that the decrease is minimal (~10%) and only 2.9% of the variation is accounted for. As sericea canopy cover increases, we indicate a significant increase in forb canopy cover, which does not include sericea. While not directly comparable, this may be partially explained by the positive correlation found between invasive and native species when viewed at large-scales using observational studies (Fridley et al., 2007). Additionally, a major challenge of invasive plant management is that the control methods themselves sometimes cause more harm to the native plant community, than the invasion alone (Rinella et al., 2009). For example, the application of broadleaf selected herbicides on an alluvial-fan grassland in Montana for leafy spurge (*Euphorbia esula*) control proved to exacerbate the problem by reducing the abundance of native-forbs and ultimately increasing leafy spurge production (Rinella et al., 2009). However, our results from the TGP indicated that sericea management had little to no negative impacts on native forbs and no long-term impacts on sericea. That the TGP had a goal of applying herbicides in a manner that would maximize sericea control while minimizing collateral damage to native species and used certain application methods to help achieve that goal, may at least partially explain this. The conservation-minded approach to the herbicide applications on the TGP may also explain why we see no additive invasion mitigation, although this remains untested. While herbicides typically provide short-term control of most invasive weeds, but without repeated application, weeds often re-establish quickly (Sheley et al., 2011). However, in our case, even with multiple herbicide applications, sericea is still largely present, as our plots received an average of 2.56 herbicide applications (range = 0-8). Herbicides may be most effective when used to address small patches of invasive species, early in the invasion, or by inhibiting the spread of large patches by "attacking the advancing front" (Rinella et al. 2009; Sheley et al., 2011). It should be noted the TGP performs management activities in order to maintain the resilience of what is a relatively intact landscape. This being said, management methods that result in large directional changes, are not expected.

Sustainable invasive plant management is most likely to be achieved when the underlying cause of invasions is repaired (Sheley and Smith 2012). Previous research indicated that pyric herbivory, which restores the historic fire/grazing interaction, performed better as an invasion mitigation approach for sericea when compared to traditional management over a six-year study period (Cummings et al. 2007). Upon resampling those study pastures, we find that the trend holds after 19 years of experimental research. Both treatments experienced equal grazing pressure and equal amounts of fire, with the only difference being the timing and pattern of the fire. When individual patches within a pasture are burned, it results in focalized grazing on that patch, until the next patch is burned. The interaction between fire and grazing (pyric herbivory) slows the invasion of sericea, as grazing animals that select for burned patches in the patch burn pastures are likely less selective at the species level when compared the large extent of the burned area in the traditional management treatment. (Cummings et al. 2007). When fire homogeneously occurs across the entire area available for grazing, the interaction between fire and grazing is absent (Allred et al., 2011). In tallgrass prairie, cattle and bison both select for the most recently burned patch.

Vegetation composition on tallgrass prairie pastures after long-term grazing by bison and cattle are shown to be similar and measurable differences are relatively minor (Towne et al., 2005). In fact, a comparative ecological study found that the primary driver of grazing behavior was an attraction to recently burned areas for both species, with the only real difference being the response to thermal stress (Allred et al., 2013). In our study, there are no difference in sericea canopy cover between the bison and cattle unit. Using other herbivores (i.e. sheep, goats, pronghorn) that are more tolerant of tannins in their diet remains a viable option to provide even greater control of sericea in this region that is primarily grazed with cattle.

Restoring fire to effectively manage an ecosystem is dependent on many variable characteristics of the disturbance regime, including season, intensity and frequency (Fuhlendorf et al., 2011; Limb et al., 2016). In the Flint Hills ecoregion of Oklahoma and Kansas, most prescribed fires are frequent (often annual) and conducted in the spring (late March to early April) and this limited fire season has been associated with the invasion of sericea (Cummings et al. 2007). It has been proposed that varying fire seasonality to include growing season fires may inhibit the invasion (Cummings et al., 2007), but long-term research from both sites suggest it had minimal influence. Following 19 years of experimental research at the OSURRS, our results show no statistical difference in sericea cover between dormant season and growing season burn patches where the fires occurred once every 3 years (Figure 8). In the pyric herbivory treatment pastures at the OSURRS, growing season fire occurred between July and October with 71.4% occurring July and August (Table 1). At the TGP, increasing the number of growing season burns has no effect on sericea canopy cover, including as many as 7 burns over 21 years (Figure 8) with 71.6 % of growing season fires occurring in August and September (Table 1). It is possible that only burning in a certain month within the growing season would produce differing results. However, severely limiting the timing of burns can result in not being able to get burns conducted due to weather, labor constraints, other unforeseen circumstances, etc. We did not evaluate the effect of annual growing season fire on sericea due to the challenges of integrating that treatment into a livestock production objective.

The spatial and temporal scale, at which ecological processes and patterns are observed, often creates varying results (Levin 1992; Leibold et al., 2004). When viewed from an invasion ecology perspective, the previous statement holds true as research conducted at varying spatial and temporal tend to result in differing conclusions on the relationship between diversity and invasion, creating the "Invasion Paradox" (Fridley et al. 2007). Traditional rangeland science often involves answering large-scale questions using relatively small-scale methods often resulting in conclusions that do not correctly extrapolate to large-scale landscapes (Fuhlendorf et al. 2012; Fuhlendorf and Brown 2016). Species invasion, like most rangeland issues, is best understood from studies at multiple scales (Fuhlendorf et al. 2012) and the use of both experimental and observational research at differing spatiotemporal scales will likely result results that more accurately address real world problems (Fridley et al. 2007). The link between science and management may be the weakest when attempting to address issues that occur at broad spatial scales (Stocker, 2004). When science on species invasion is limited to small-scale, tightly controlled studies, large-scale patterns of effective management and non-target damage may be difficult to determine, making the connection between science and application challenging (Fuhlendorf and Brown 2016).

In our study, we used both a long-term controlled experiment and an observational study on landscapes where ecological processes are restored in order to promote diversity. Restoration of pyric herbivory with bison and cattle provided the greatest invasion mitigation for an invasive legume when compared to traditional management methods at landscape scales. Comparisons of both sites where one included herbicide and one did not, suggested that any additional invasion control from conservation-based herbicide application lasted only about one year and there was no evidence of long-term benefits. Additional research should evaluate other methods of herbicide application, as well as other herbivores to determine efficacy and non-target damage. Managing an invasive species and preserving native plant diversity simultaneously continues to be a challenge in native ecosystems, including the tallgrass prairie region of North America.

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TABLES AND FIGURES

Table 1. The number of burns in each month during a 21-year (1997-2018) observational study at the Joseph H. Williams Tallgrass Prairie Preserve and during a 19-year (1999-2018) experimental study at the Oklahoma State University Range Research Station.

	TGP			OSURRS		
	# of Burns	% of Total Burns		# of Burns	% of Total Burns	
Month		**Dormant Season**	**Growing Season**		**Dormant Season**	**Growing Season**
January	5	0.9	-	0	-	-
February	8	1.5	-	10	7.7	-
March	207	38.3	-	29	22.1	-
April	157	29.1	-	36	27.4	-
May	12	-	2.1	0	-	-
June	0	-	-	0	-	-
July	23	-	4.3	23	-	17.5
August	58	-	10.6	17	-	11.5
September	38	-	7.1	5	-	3.1
October	3	-	0.6	14	-	10.7
November	9	1.6	-	0	-	-
December	21	3.9	-	0	-	-
Totals	541	75.2	24.8	131	57.3	42.7

Table 2. Response variables and models used to determine the effects of management on sericea lespedeza (*Lespedeza cuneata*) and the native plant community on the Joseph H. Williams Tallgrass Prairie Preserve from 1997-2018. Fabaceae canopy cover percentage and Asteraceae canopy cover percentage refer to the canopy cover of species within those families, that are on the list of selected forbs.

Response Variables	Models
Sericea Lespedeza Canopy Cover %	Time Since Fire
Total Forb Canopy Cover %	Total Burns
Total Grass Canopy Cover %	Total Growing Season Burns
Total Bare Ground Canopy Cover %	Time Since Spray
Total Selected Forb Canopy Cover %	Total Sprays
Total Selected Forb Richness	Time Since Fire + Total Burns
Fabaceae Canopy Cover %	Time Since Spray + Time Since Fire
Asteraceae Canopy Cover %	Time Since Fire + Total Growing Season Burns
	Time Since Fire + Time Since Spray + Total Sprays

Table 3. Competitive generalized linear models ($\Delta AIC_c \leq 2$) shown to be significant using an analysis of variance (ANOVA) and the estimate values from the model summary, used to determine the effect of sericea lespedeza (*Lespedeza cuneata*) management practices on sericea and the native plant community over a 21- year (1997-2018) observational study at the Joseph H. Williams Tallgrass Prairie Preserve.

Response Variable	Model	Δ AIC_c	df	Weight	Estimate	p-value
Grasses	Time Since Spray + Time Since Fire	0.0	4	.559	< -.001 .002	< .001
	Time Since Fire + Time Since Spray + Total Sprays	1.3	5	.289	.001 < -.001 -.011	.016
Bare Ground	Time Since Fire	0.0	3	.33	-.002	< .001
	Time Since Fire + Total Burns	0.8	3	.22	-.002 -.005	< .001
	Time Since Spray + Time Since Fire	1.3	4	.17	< -.001 < -.001	< .001
	Time Since Fire + Time Since Spray + Total Sprays	1.5	5	.16	< -.001 < -.001 < -.001	< .001
	Time Since Fire + Total Growing Season Burns	2.0	4	.12	< -.001 < -.001	< .001
Total Selected Forb Richness	Total Sprays	0.0	3	.238	.246	.041
Fabaceae	Total Sprays	0.0	3	.237	.015	.025
	Time Since Spray	0.1	3	.232	< -.001	.024
Asteraceae	Total Growing Season Burns	0.0	3	.283	.001	.028

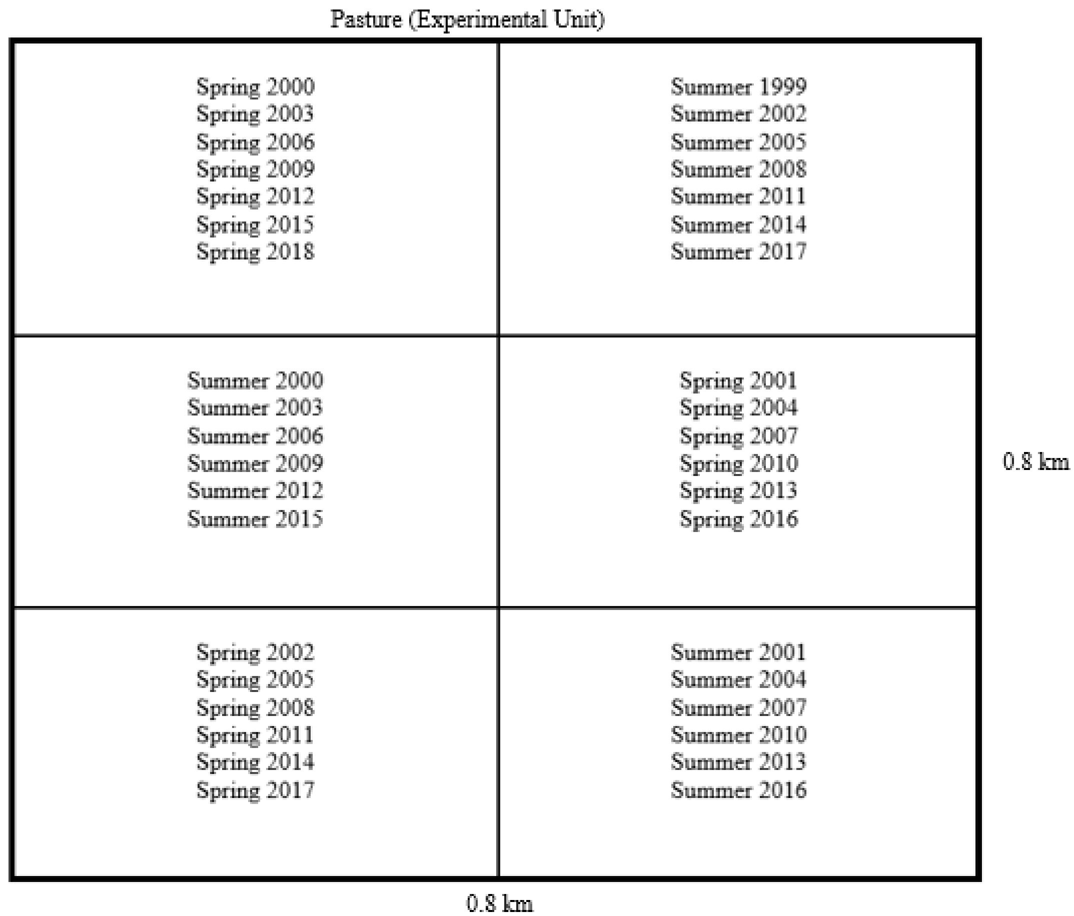

Figure 1. The pyric herbivory treatment schedule for the three (0.8 km x 0.8 km) pastures receiving the pyric herbivory treatment at the Oklahoma State University Range Research Station.

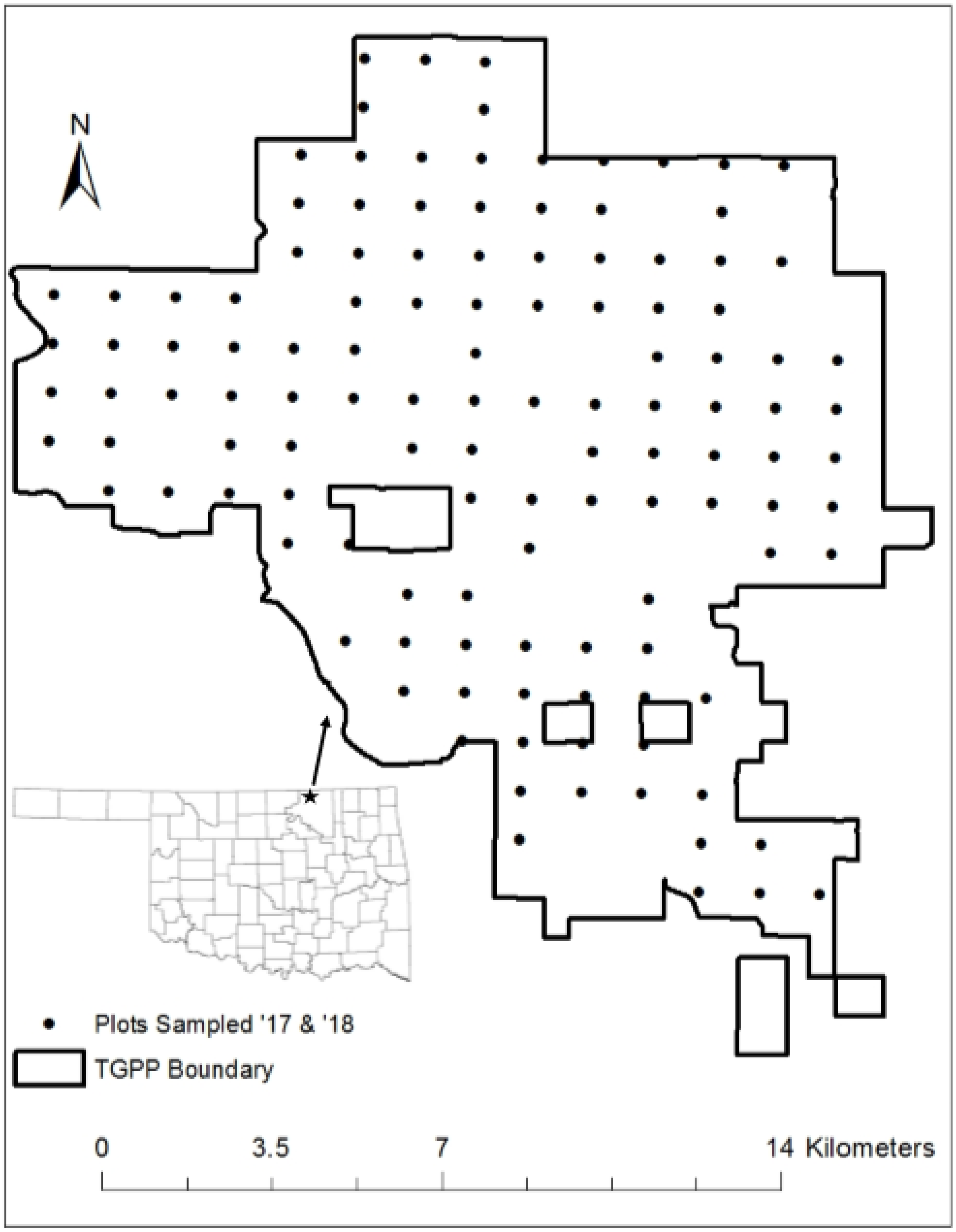

Figure 2. Location of the 122-UTM grid permanent 10 x 10m vegetation monitoring plots sampled in June of 2017-18 at the Joseph H. Williams Tallgrass Prairie Preserve.

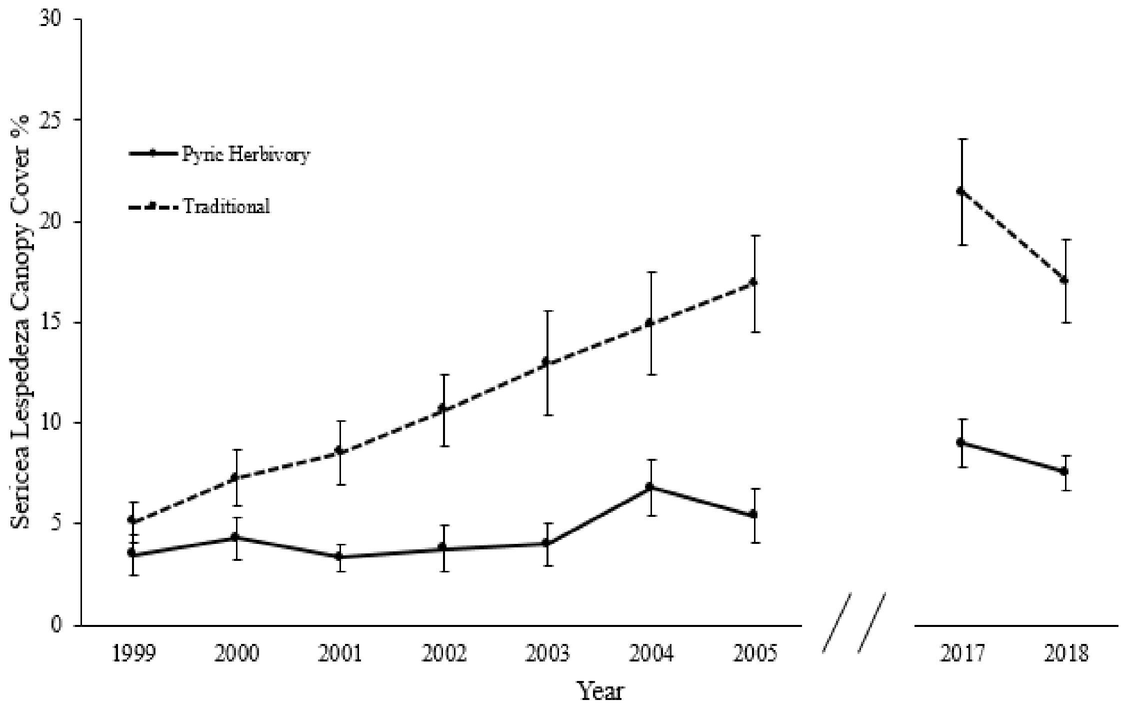

Figure 3. Sericea lespedeza (*Lespedeza cuneata*) invasion over time in the pyric herbivory and traditionally managed treatment pastures after 19 years at the Oklahoma State University Range Research Station. Data from 1999-2005 is previously published data (Cummings et al. 2007). Error bars are equal to 1 SE.

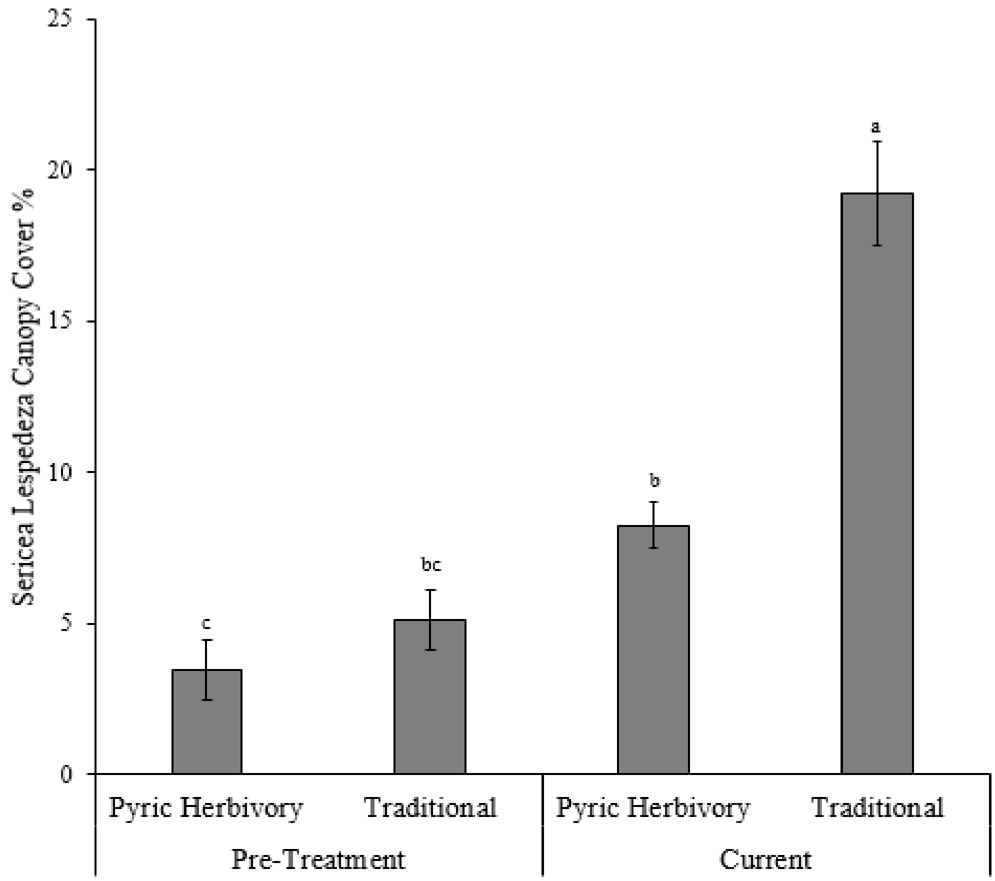

Figure 4. Pre-treatment (1999) and current (2017-2018) sericea lespedeza (*Lespedeza cuneata*) canopy cover percent in the pyric herbivory and traditionally managed treatment pastures at the Oklahoma State University Range Research Station. Bars with differing letters indicate a difference in means (P<0.05). Error bars are equal to 1 SE.

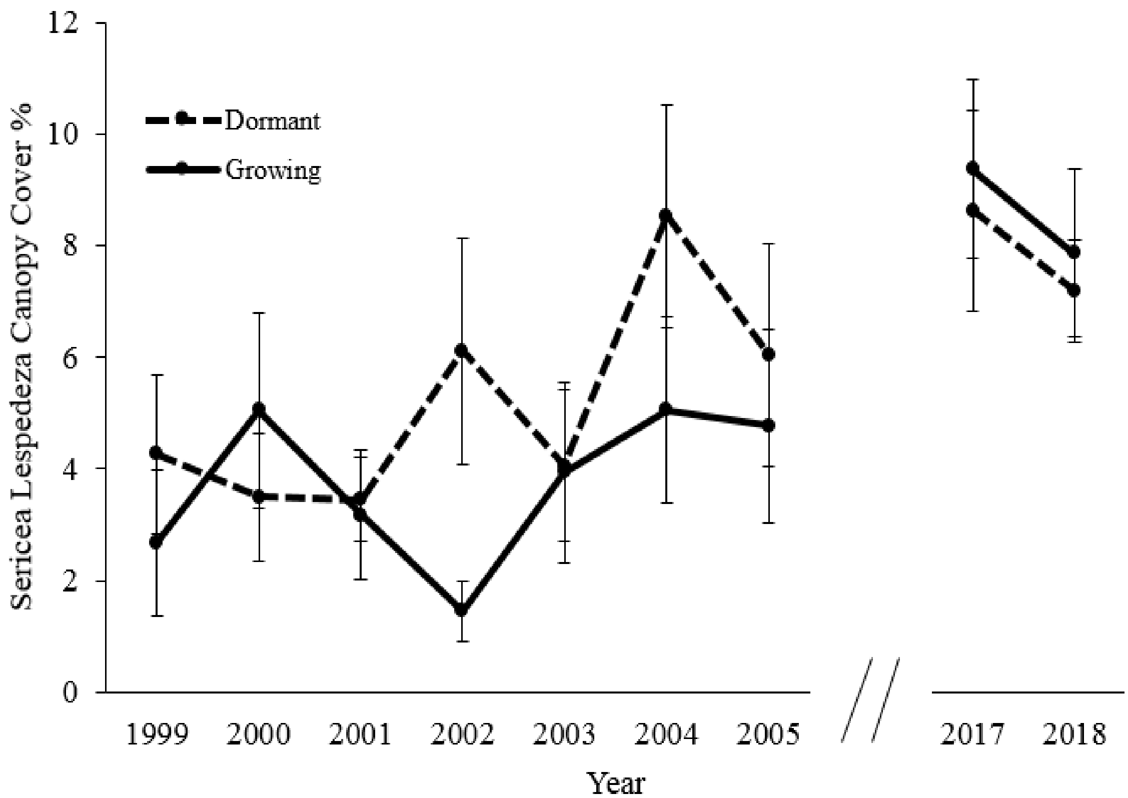

Figure 5. Sericea lespedeza (*Lespedeza cuneata*) invasion over time in the dormant season fire patches and the growing season fire patches in the pyric herbivory treatment pastures after 19 years of a controlled experiment where dormant and growing season fire has been applied to the same patch every third year at the Oklahoma State University Range Research Station. Data from 1999-2005 is previously published data (Cummings et al. 2007). Error bars are equal to 1 SE.

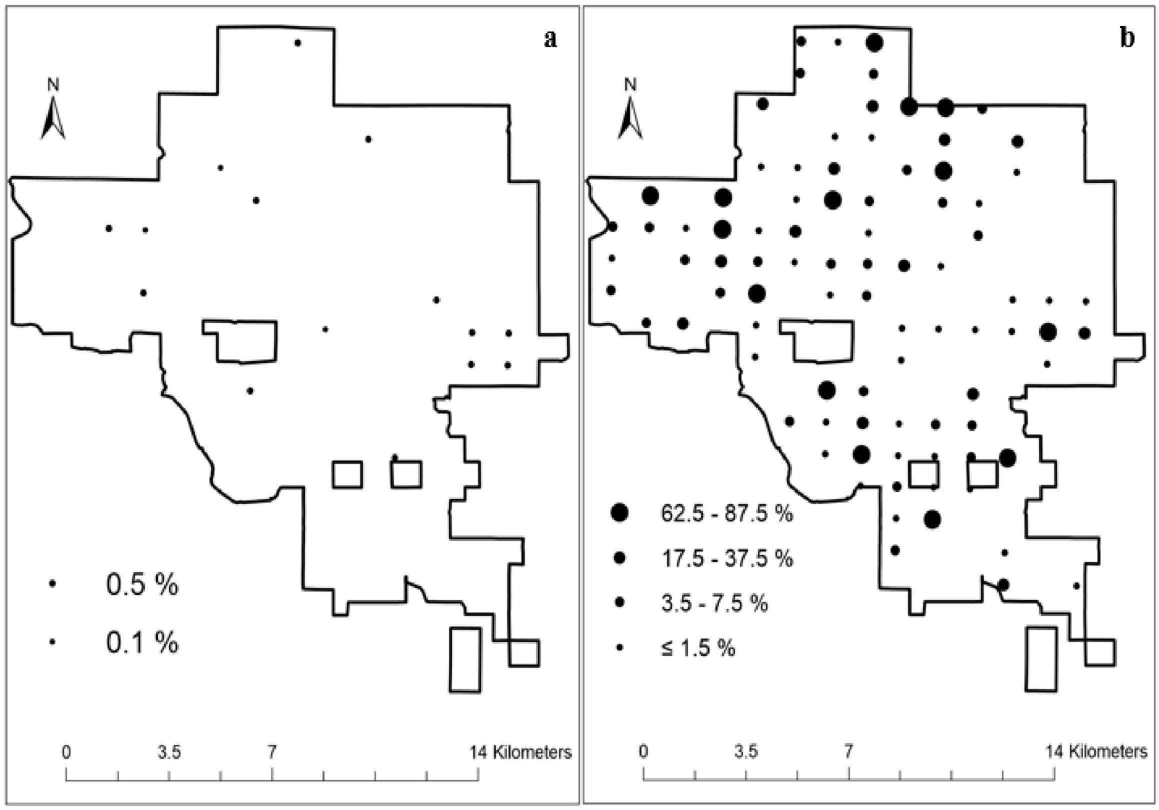

Figure 6. Location and maximum amount of sericea lespedeza (*Lespedeza cuneata*) canopy cover found during the historic sampling period (1997-2000) (**a**) and the current sampling period (2017-2018) (**b**) for each sampling point at the Joseph H. Williams Tallgrass Prairie Preserve.

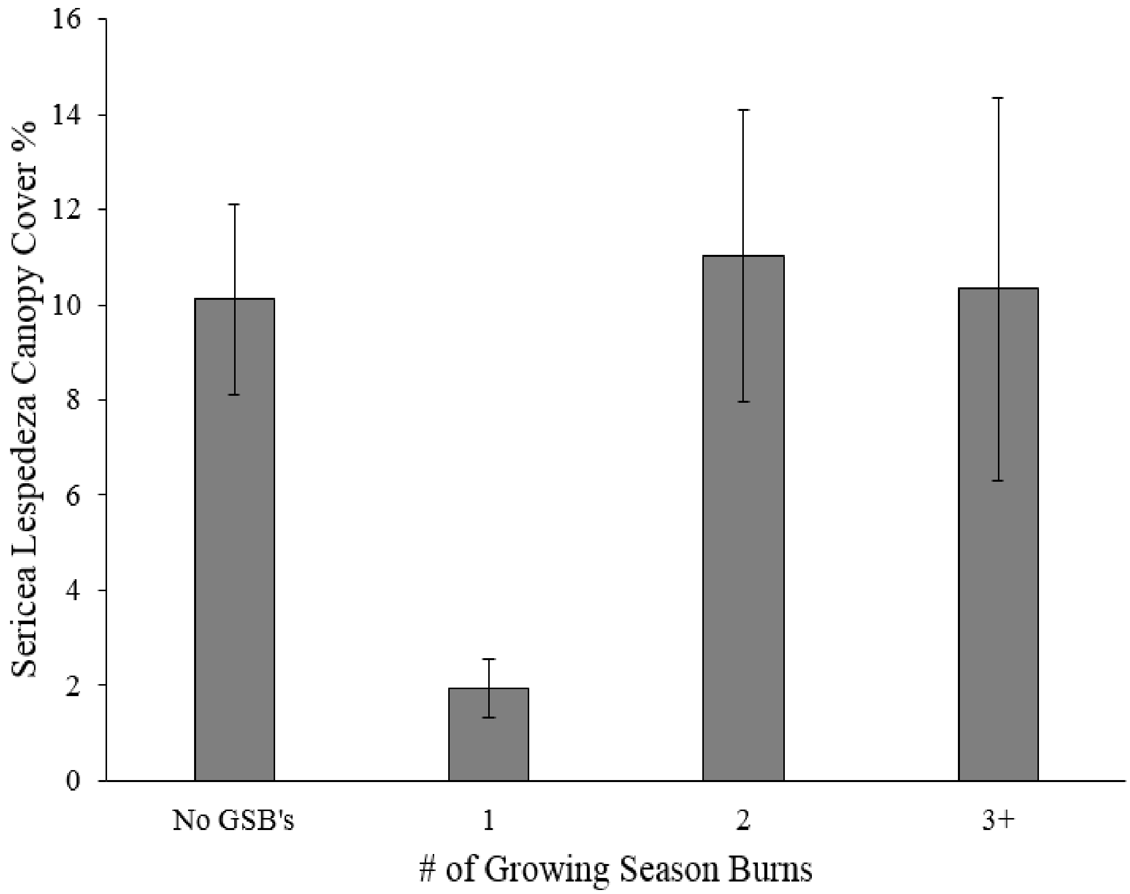

Figure 7. Sericea lespedeza (*Lespedeza cuneata*) canopy cover with differing amounts of growing season burns over a 21-year (1997-2018) observational study period at the Joseph H. Williams Tallgrass Prairie Preserve. Error bars are equal to 1 SE.

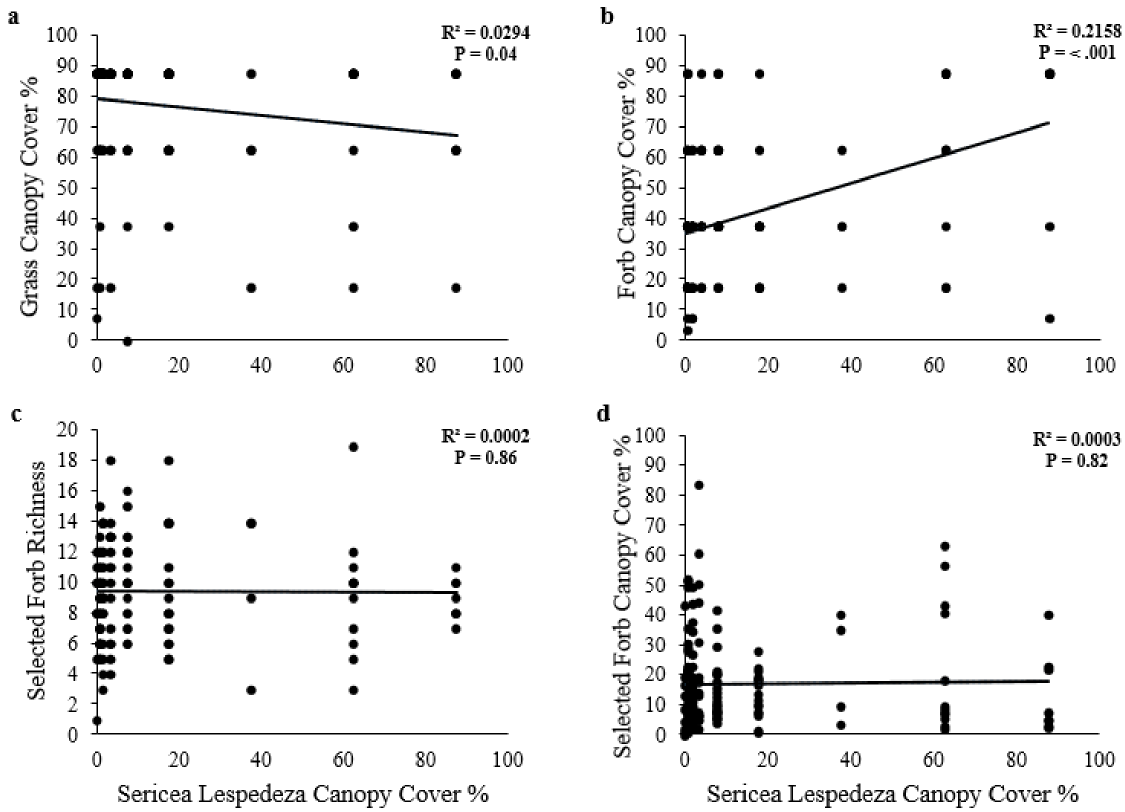

Figure 8. Linear regression analysis of sericea lespedeza (*Lespedeza cuneata*) canopy cover and grass canopy cover (**a**), forb canopy cover (**b**), selected forb richness (**c**) and selected forb canopy cover (**d**) in plots containing sericea lespedeza during a 21-year (1997-2018) observational study on the Joseph H. Williams Tallgrass Prairie Preserve.

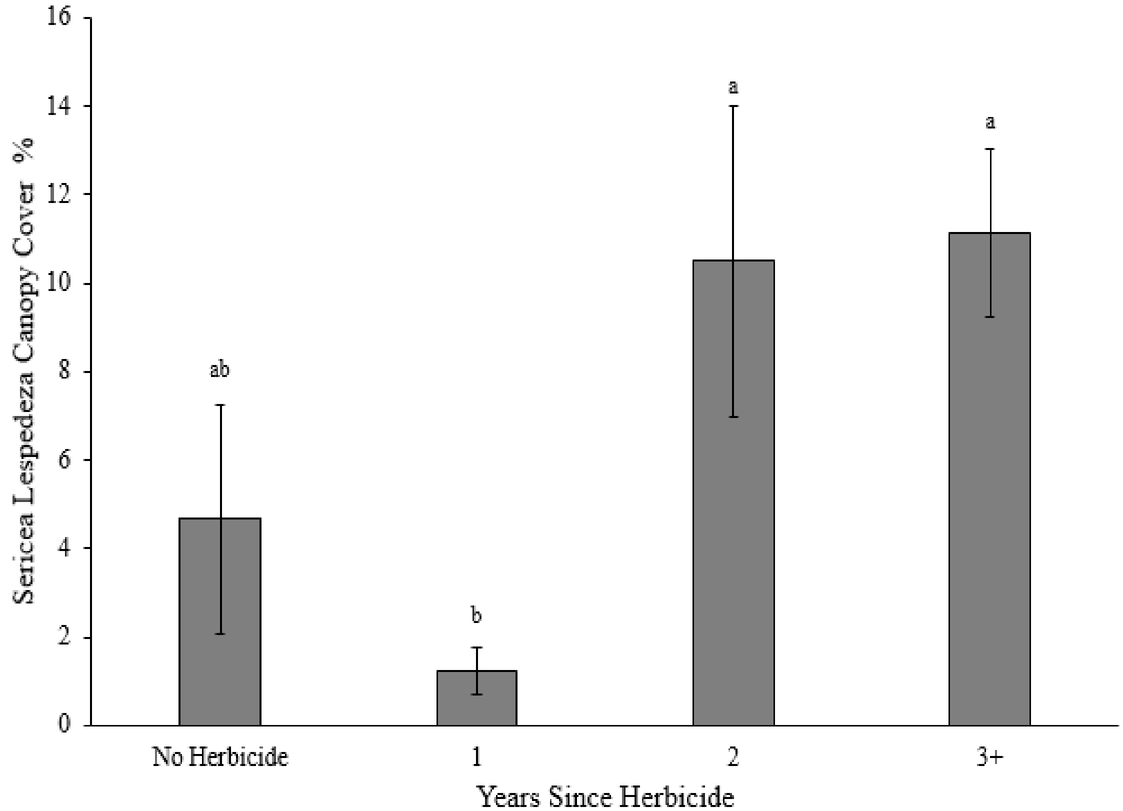

Figure 9. Sericea lespedeza (*Lespedeza cuneata)* canopy cover with differing times since herbicide application over a 21-year (1997-2018) observational study at the Joseph H. Williams Tallgrass Prairie Preserve. Bars with differing letters indicate a difference in means ($P<0.05$). The "No Herbicide" bar constitutes plots that have not received an herbicide treatment in the 21-year study period. Error bars are equal to 1 SE.

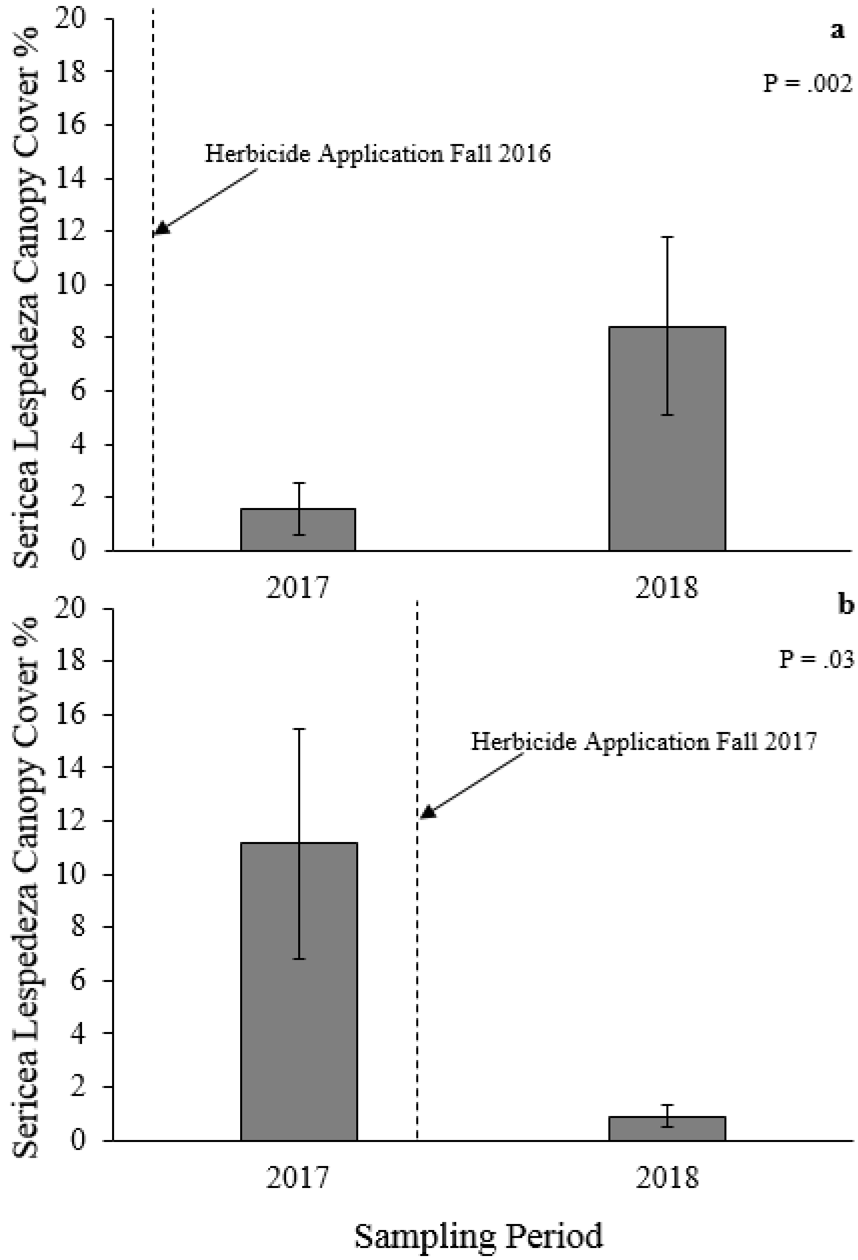

Figure 10. Sericea lespedeza (*Lespedeza cuneata*) canopy cover in plots (n=18) with an herbicide application in 2016 (**a**) and plots (n=20) with an herbicide application in 2017 (**b**) at the Joseph H. Williams Tallgrass Prairie Preserve. Error bars equal to 1 SE.

CHAPTER II

IMPORTANCE OF FORBS AND AN INVASIVE LEGUME IN CATTLE AND BISON DIETS

ABSTRACT

Understanding the diet composition and dietary habits of herbivores using rangeland is fundamental to rangeland management. In grasslands of the Great Plains, a majority of plant biomass is provided by monocotyledonous species (mostly grasses with some sedges and rushes) while dicotyledonous species (forbs and woody plants) provide a majority of the species diversity. Forbs are critical to floral diversity and many are readily eaten by livestock. We assess the diets of cattle and bison using the *trn*L meta-barcoding approach on a large tallgrass prairie landscape managed to promote diversity but that has been invaded by sericea lespedeza (*Lespedeza cuneata*). Our results indicate that dicots provided 70-80% of the dietary protein throughout the growing season for both cattle and bison. Forbs in the legume family provided 60-65% of protein intake for both bison and cattle. A non-native legume in the genus Lespedeza, likely sericea, provided an average of 25-30% of the bison and cattle protein intake throughout the

growing season.

INTRODUCTION

Understanding the diet composition and dietary habits of herbivores using rangeland, is fundamental to grazing management (Holechek et al. 1982; Olsen and Hansen, 1997). Accurate knowledge of diet and selection is important to forage allocation and the selection of the most appropriate kind and class of grazing animals (Holechek et al. 1982). Diverse plant communities and their spatial and temporal variation across landscapes, often complicates the determination of composition and diet quality of herbivores on large landscapes (Wofford et al. 1985).

In grasslands of the Great Plains, the majority of plant biomass is provided by monocotyledonous species (mostly grasses with some sedges and rushes) while dicotyledonous species (forbs and woody plants) provide the majority of species diversity (Collins et al. 1998; Towne and Kemp 2003, 2008). Forbs are critical to floral diversity, which in turn provides key nutritional and structural elements for many wildlife species and pollinators (Koerth, 1996; Fründ et al. 2010). Livestock species readily consume many forbs and they are often important to overall diet quality and in limiting nutrient deficiencies (Heitschmidt and Taylor, 1991; Huston and Pinchak, 1991).

Despite evidence for forbs playing an integral role in the diets of livestock, a survey of Great Plains ranchers shows a low preference for forbs on lands they manage (Becerra et al. 2017). Many traditional rangeland management practices promote the simplification and homogenization of rangelands, which in turn decreases heterogeneity and plant species diversity (Fuhlendorf and Engle, 2001). The reduction of forage species diversity could result in lower overall diet quality for rangeland herbivores in addition to loss of habitat for many wildlife species. One of the more common rangeland simplification practices in the Great Plains is the use of broadleaf (forb) selected herbicides (Fuhlendorf et al. 2009a). In many cases, large-scale herbicide applications are conducted with the expectation that a reduction in forbs results in increased production of graminoids, leading to increased livestock gain, despite the fact that this expectation is not supported by pasture level research.

Historically, diet composition determination of rangeland herbivores relied largely on direct observations and fecal analyses, both chemically and microhistologically (Holechek et al. 1982). Microhistology, the most common of the previously stated techniques, has been shown to underrepresent forage species of high dietary quality due to those species having easily digestible cell walls (Holechek et al. 1982; Bartolome et al. 1995), which may have led to an overestimation on the reliance to graminoids of certain rangeland herbivores (Craine et al. 2015; Craine et al. 2016). Recently, DNA meta-barcoding has been applied and used in diet composition reconstruction of numerous herbivores including bison (*Bison bison* L.) (Craine et al. 2015), cattle (*Bos* spp.) (Craine et al. 2016), large African mammalian herbivores (Kartzinel et al. 2015) and primates (Quéméré et al. 2013). With respect to fecal samples, meta-barcoding can be used to quantify relative abundance of DNA of forage items (Craine et al., 2016), and when paired with knowledge of the local flora community, it can provide an alternative tool to understand different species that make up the animals diet (Valentini et al. 2009; Willerslev et al. 2014). Meta-barcoding analyses using the *trn*L approach targets the P6 loop of the chloroplast *trn*L (UAA) intron (Valentini et al. 2009). Differences in protein concentration among plants are said to be correlated with chloroplast density (Bergmann et al. 2015) and the *trn*L approach produces data which likely represents the dietary protein contributions from different plant species rather than biomass intake (Craine et al. 2016), but have paired well with biomass in previous research (Willerslev et al. 2014).

We have the unique opportunity to study the diets of cattle and bison using the *trn*L meta-barcoding approach on a large tallgrass prairie landscape managed to promote diversity but that has been invaded by sericea lespedeza (*Lespedeza cuneata* [Dum.-Cours G. Don]), hereafter referred to as sericea, an invasive perennial legume. Sericea produces tannins, which become increasingly concentrated as the plant ages and is thought to provide little to no contributions to the diet of cattle and bison (Mosjidis et al., 1990). On tallgrass prairie where livestock production is the dominant land use objective, little focus has been placed on forbs, and conservation approaches to promote plant diversity are often considered counter to livestock production objectives (Fuhlendorf et al. 2012). Protein is a limiting factor in tallgrass prairie, and herbivores are often protein limited (McCollum and Horn, 1990; Craine et al. 2010). The *trn*L meta-barcoding approach can provide more data about dietary contributions related to protein intake of forbs in the diet of herbivores on tallgrass prairie. Our specific objective was to use the *trn*L meta-barcoding approach to determine the importance of forbs, dicotyledonous plants as a whole, and sericea in diets of cattle and bison during the growing season in a patch-burned tallgrass prairie ecosystem.

MATERIALS AND METHODS

Study Area

Data collection occurred at The Nature Conservancy's Joseph H. Williams Tallgrass Prairie Preserve (TGP) in Osage County, Oklahoma, approximately 21 kilometers north-northwest of Pawhuska, Oklahoma. The TGP is part of the largest intact portions of tallgrass prairie in North America and is located within the southern extent of the Flint Hills ecoregion. The TGPP is split into a ~9500-hectare bison unit and ~5000-hectare cattle unit. Bison on the TGPP are grazed year round and are free to move across the entire bison unit (Hamilton 2007). The cattle on the TGP are yearling crossbred stocker cattle in an intensive early stocking (IES) grazing system. With the exception of salt and trace mineral supplementation, the grazing animals at the TGP receive no dietary supplements during the growing season. The TGP uses patch burning across both units in order to maintain the historic fire and grazing interaction by burning patches on a random basis with varying temporal and spatial factors. Sericea has invaded the TGP and currently makes up ~8.5% of the vascular plant canopy cover across the TGP (Sherrill et al. 2019, IN PROCESS). Despite large scale control efforts (selective herbicide applications) put into place to control sericea, the native plant community remains relatively unharmed (Sherrill et al. 2019, IN PROCESS) and intact as 763 vascular plant species have been recorded across the TGP (Palmer, 2007).

Data Collection

We collected fecal samples from cattle and bison in April, June and September. In June and September of 2017, we collected three aggregate samples from discrete bison herds across the bison unit at the TGP and three aggregate samples from three cattle herds on separate experimental landscapes. In April, June and September of 2018, we collected three aggregate samples from each grazing species for each time period. This results in a total of three samples for April, six samples for June and six samples for September for each herbivore species. As the bison herd is not separated by fences, during each sampling period, we chose to select three different groups of bison that where spatially separated by at least 3 kilometers across the preserve to sample from. At each sampling period, we obtained 0.25 kg of fresh fecal material from 10 separate adult animals and homogenized them to create a representative aggregate "herd sample". Upon homogenization, we immediately put the samples on ice and later into the freezer (<180 minutes post collection).

DNA Meta-barcoding

We sent the frozen fecal samples to Jonah Ventures (Boulder, CO) for plant based genomic DNA extraction where procedures follow those outlined in Craine et al. 2015, which provided operational taxonomic unit (OTU) from the GenBank® database. We used all OTU's for each sample, with the exception of *Pinus* OTU, which we excluded from analyses. We also sent a voucher specimen of sericea collected from the TGP in

July 2017 to Jonah Ventures. The sericea voucher shows that 99.4% of all OTU reads can be attributed to OTU403 (*Lespedeza pilosa* [Thunb. Siebold and Zucc.] Eastern Asian descent) (92.8%) and OTU510 (*Lespedeza* [Includes 19 species within *Lespedeza*, including sericea, all Eastern Asian descent]) (6.6%). We will consider the summation of OTU403 and OTU510 to be a measure of plant(s) from the genus *Lespedeza* of Eastern Asian descent, hereafter referred to as EA Lespedeza and all non-native.

Statistical Analyses

We analyzed the count data produced from the *trn*L approach at Jonah Ventures as relative read abundance percentage (RRA), i.e. total reads for an OTU in relation to total reads per sample. We did not calculate electivity indices because the trnL approach does not sample exact forage proportions used, rather it calculates relative dietary protein contributions from differing plant species (Craine et al. 2016). We performed an arcsin(square root) transformation to all percentage data prior to analysis. We used a one –way ANOVA ($\alpha = 0.05$) and the Tukey's HSD ($\alpha = 0.05$) as a post hoc test to compare the RRA's for differing seasonal averages, plant functional groups, plant families and speciesfor each herbivore. We performed all statistical analyses within the program, R (R Core Team, 2016).

RESULTS

Our results show that for both cattle ($P<.001$) and bison ($P<.001$), the RRA was significantly higher for dicots than monocots throughout the growing season (Figure 1). Across the entire growing season for the cattle and the bison, the seasonal average dicot RRA was 81.4% and 71.8%, respectively. Within the cattle samples, the dicot RRA was significantly higher during the September sampling period than when compared to that of the April and June samples.

At the family classification, Poaceae (grasses) made up >98% of all monocot OTU reads and Fabaceae (legumes) provided a majority of the dicot OTU reads for both cattle and bison. In cattle, the seasonal RRA of Fabaceae (65.2%) was significantly higher ($P<0.001$) than that of Poaceae (18.3%) and that of all other dicots (16.2%) ($P<0.001$) throughout the growing season (Figure 2). Within the cattle samples, there was no statistical differences between the classifications in the April sampling period (Figure 2). In bison, the seasonal average Fabaceae RRA (59.4%) was significantly higher ($P>0.001$) than that of Poaceae (28%) and all other dicots (12.3%) ($P>0.001$) throughout the growing season (Figure 2). The seasonal average Poaceae RRA was higher ($P>0.001$) than that of all other dicots in bison throughout the growing season (Figure 2).

The RRA percentage of EA Lespedeza show seasonal averages being 26.9% for cattle and 27.2% for bison (Figure 3). For bison, the RRA percentage of EA Lespedeza, was significantly higher in the April sampling period than during the June and September period ($P<0.05$) (Figure 3).

DISCUSSION

Understanding the diet composition and habits of herbivore using rangelands is fundamental to grazing management (Holechek et al. 1982; Olsen and Hansen, 1977) and diverse plant communities often complicate determining diet composition (Wofford et al. 1985). Forbs provide a majority of species diversity in the grasslands of the Great Plains (Collins et al. 1998; Towne and Kemp 2003, 2008) and many of them are readily eaten by livestock species, which improves diet quality and limits nutrient deficiencies (Heitschmidt and Taylor, 1991;Huston and Pinchak, 1991). Despite evidence for their importance, ranchers in the Great Plains, where livestock production is the dominant land use objective, do not favor forbs (Becerra et al. 2017). Our data suggests that dicots, especially those in the family of Fabaceae and the genus *Lespedeza* of Eastern Asian descent are making significant contributions to the diets of bison and cattle at the TGP. Assuming that RRA provides a measure of relative protein intake, the average protein intake in the growing season from dicots was 81.4% in cattle and 71.1% in bison. The Poaceae family provided a growing season average protein intake of 18.3% in cattle and 28% in bison while the Fabaceae family provided 65.2% and 59.4%, respectively. Plant(s) within the genus *Lespedeza* of Eastern Asian descent provided a growing season average protein intake of 26.9% in cattle and 27.7% in bison. In April, *Lespedeza* of Eastern Asian descent provided ~50% of the protein intake for bison. While we do not directly compare cattle to bison, it appears that there are no major differences in dominant sources of dietary protein intake between the two herbivores.

Previous diet analyses indicate that dicots make up 2-15% of bison diet (Coppedge et al. 1998; Plumb and Dodd 1993, 1994) and 8-30% of cattle diet (Plumb and Dodd 1993, 1994; Sowers et al. 2019). Possible explanations for the discrepancies when compared to our study include: differing methodology, a warming climate and a difference in forage availability. The use of microhistology, shown to underrepresent dicots (Holechek et al. 1982; Bartolome et al. 1995), in early studies may have led to an overestimation on the reliance to graminoids of certain rangeland herbivores (Craine et al. 2015; Craine et al. 2016). It has been hypothesized that with a warming climate, protein content in monocots may be decreasing, and that herbivores are self-supplementing their diets by utilizing more, higher protein dicots (Craine et al. 2015; Craine et al. 2016). However, the possibility of climatic differences being a factor over the relatively short time between these studies remains untested. Diets are largely dependent upon forage availability (Allden and Whittaker, 1970; Ungar and Noy-Meir, 1988; Bailey et al. 1996) and at the TGP monocots and dicots make up 26.7% and 70.7 % of species composition, respectively (Palmer, 2007) Further, average canopy cover of grasses and forbs are 75.3% and 37.7%, respectively for the TGP (TGP records). As a landscape managed to promote diversity, the herbivores on the TGP, may have had access to more dicots, than those in previous studies. The dietary contribution of dicots and that of the Fabaceae family shown in our study parallel results in cattle (Craine et al. 2016) and bison (Craine et al. 2015) in the southern Great Plains using similar methods.

Unresolved differentiations between species using the *tnr*L approach are typically those between closely related species (Taberlet et al. 2007). While in the same genus, sericea and the *Lespedeza* spp. native to North America, are only distantly related (Han et al. 2010). This information, paired with the fact that 99.4% of all OTU reads from our voucher specimen of sericea came from closely related species (all from Eastern Asian decent), indicates that the values reported as "EA Lespedeza" likely represent values for sericea, as it is the only *Lespedeza* sp. from Eastern Asian decent that has been reported on the TGPP (Palmer, 2007). Our results run counter to claims made by recent studies that report minor herbivory of sericea by yearling stocker steers (Lemmon et al. 2017) and a strong avoidance to sericea (Sowers et al. 2019). It should be noted that those studies where done in areas with less sericea compared to the TGPP, where sericea constitutes ~9% of plant canopy cover (Sherrill et al. 2019, IN PROCESS) and done using IES, with annual spring fire of entire pastures. The re-introduction of pyric herbivory (Fuhlendorf et al. 2009b) is shown to be a superior sericea mitigation method compared to the traditional spring burning of entire pastures (Cummings et al. 2007; Sherrill et al. 2019, IN PROCESS). The preferential grazing of sericea within the most recently burned patches is likely the primary driver of the invasion mitigation; not the direct effects of fire. If the grazing is likely driving the invasion mitigation, it is logical that we show sericea to be contributing more to the diet of cattle and bison, than is shown in a traditional fire and grazing system.

MANAGEMENT IMPLICATIONS

Our results indicate that forbs, especially those in the family Fabaceae, and likely sericea are making large contributions to the diets of cattle and bison during the growing season on patch burned tallgrass prairie. In grasslands of the Great Plains, forbs provide the majority of species diversity (Collins et al. 1998; Towne and Kemp 2003, 2008). Should upcoming research confirm our results, it may provide further indication that rangeland management in the southern Great Plains should shift focus to creating and maintaining floristic biodiversity across the landscape. The fact that the primary land use objective, of rangelands in the southern Great Plains, is livestock production should solidify that notion, as protein begets protein.

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FIGURES

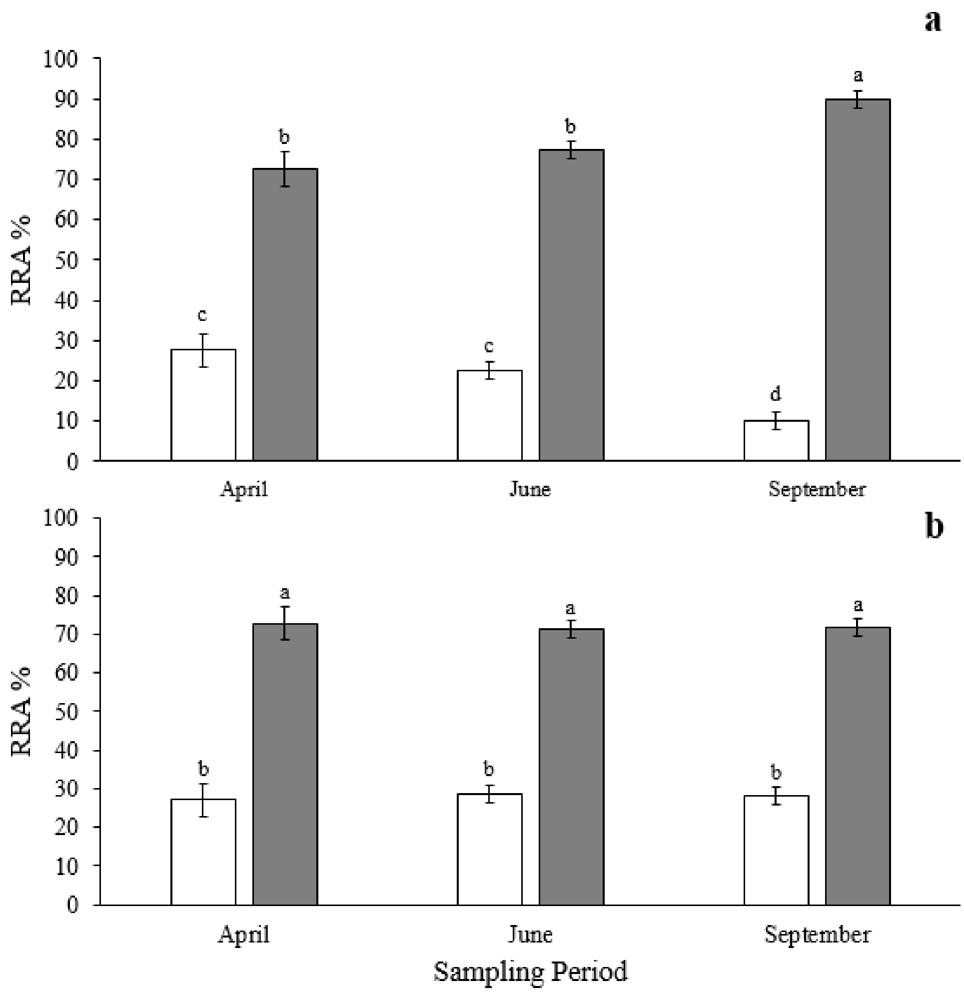

Figure 1. The percentage of relative read abundance (RRA) of (monocots; open bars) and (dicots; closed bars) in the diets of cattle (*Bos* spp.) (**a**) and bison (*Bison bison*) (**b**) at the Joseph H. Williams Tallgrass Prairie Preserve determined using the *trn*L meta-barcoding approach in 2017 and 2018. Bars with differing letters indicate a significant difference in the means ($P<0.05$). Error bars are equal to 1 SE.

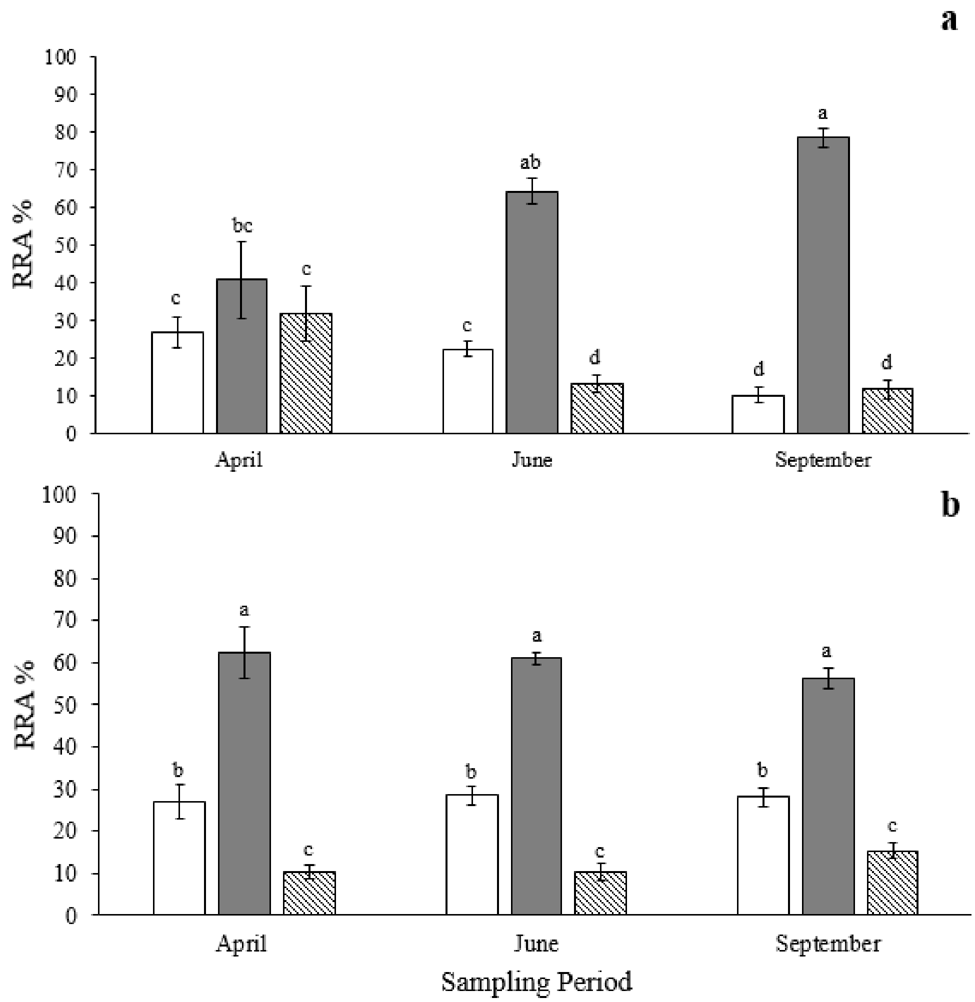

Figure 2. The percentage of relative read abundance (RRA) from (Poaceae; open bars), (Fabaceae; closed bars) and (all other dicots; hashed bars) in the diets of cattle (*Bos* spp.) (**a**) and bison (*Bison bison*) (**b**) at the Joseph H. Williams Tallgrass Prairie Preserve using the *trn*L meta-barcoding approach in 2017 and 2018. Bars with differing letters indicate a significant difference in the means ($P<0.05$). Error bars are equal to 1 SE.

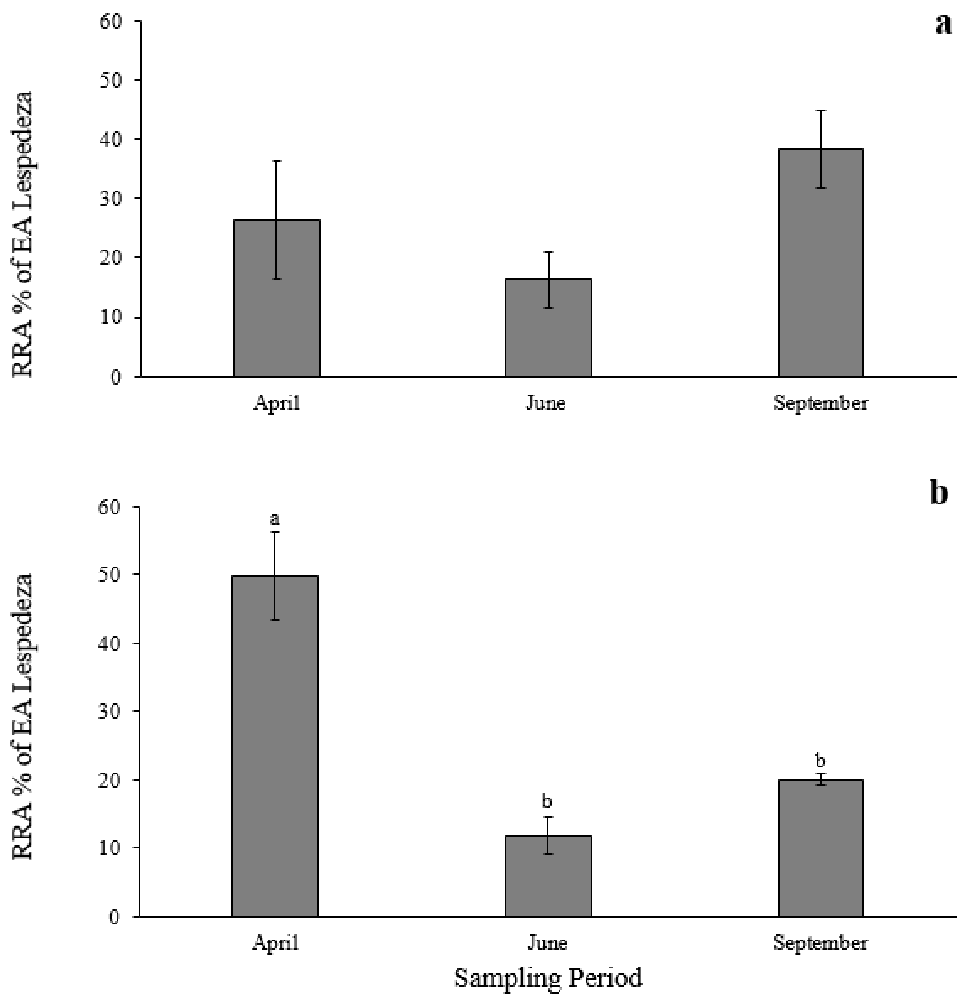

Figure 3. The percentage of relative read abundance (RRA) of EA Lespedeza in the diets of cattle (*Bos* spp.) (**a**) and bison (*Bison bison*) (**b**) at the Joseph H. Williams Tallgrass Prairie Preserve using the *trn*L meta-barcoding approach in 2017 and 2018. Bars with differing letters indicate a significant difference in the means ($P<0.05$). Error bars are equal to 1 SE.

APPENDICES

Cover Class	**% range**
1	trace
2	< 1
3	1–2
4	2–5
5	5–10
6	10–25
7	25–50
8	50–75
9	75–100

Appendix A. Cover classes and their corresponding percentage ranges used to quantify percent cover at the 100 m^2 permanent vegetation monitoring plots at the Joseph H. Williams Tallgrass Prairie Preserve in Osage County, Oklahoma.

Latin Name	**Common Name**	**Family**
Acacia angustissima	Prairie Acacia	Fabaceae
Ambrosia psilostachya	Western Ragweed	Asteraceae
Amorpha canascens	Leadplant	Fabaceae
Apocynum cannabinum	Prairie Dogbane	Apocynaceae
Arnoglossum plantagineum	Indian Plantain	Asteraceae
Artemesia ludoviciana	Sage Milkwort	Asteraceae
Asclepias stenophylla	Threadleaf Milkweed	Apocynaceae
Asclepias syriaca	Common Milkweed	Apocynaceae
Asclepias tuberosa	Butterfly Milkweed	Apocynaceae
Asclepias viridis	Antelope-horn Milkweed	Apocynaceae
Baptisia alba	White Wild Indigo	Fabaceae
Baptisia australis	Blue Wild Indigo	Fabaceae
Baptisia bracteata	Cream Wild Indigo	Fabaceae
Chamaecrista fasciculata	Showy Partridge Pea	Fabaceae
Coreopsis grandiflora	Bigflower Coreopsis	Asteraceae
Dalea candida	White Prairie Clover	Fabaceae
Dalea purpurea	Purple Prairie Clover	Fabaceae
Desmanthus illinoensis	Illinois Bundleflower	Fabaceae
Desmodium sessilifolium	Sessile-leaved Tickclover	Fabaceae
Echinacea pallida	Pale Purple Coneflower	Asteraceae
Erigeron strigosus	Daisy Fleabane	Asteraceae
Eryngium yuccifolium	Rattlesnake Master	Apiaceae
Euphorbia marginata	Snow-on-the-Mountain	Asteraceae
Helianthus maximilianii	Maximillion Sunflower	Asteraceae
Helianthus mollis	Ashy Sunflower	Asteraceae
Lespedeza capitata	Round-Head Lespedeza	Fabaceae
Lespedeza cuneata	Sericea Lespedeza	Fabaceae
Lespedeza virginica	Slender Lespedeza	Fabaceae
Liatris aspera	Rough-Blazing Star	Asteraceae
Liatris punctata	Dotted-Blazing Star	Asteraceae
Liatris pycnostachya	Prairie-Blazing Star	Asteraceae
Mimosa quadrivalvis	Catclaw Sensitivebriar	Fabaceae
Oenothera filliformis	Large-Flower Gaura	Onagraceae
Psoralidium tenuiflorum	Scurf Pea	Fabaceae
Silphium laciniatum	Compass Plant	Asteraceae
Solidago Canadensis	Canada Goldenrod	Asteraceae
Tephrosia virginiana	Goat’s Rue	Fabaceae
Vernonia sp.	Iron Weed	Asteraceae

Appendix B. The list of “selected forbs” that cover class data was collected for at the Joseph H. Williams Tallgrass Prairie Preserve.

Response Variable	Model	Δ AIC$_c$	df	Weight	Estimate	p-value
Sericea Lespedeza	Total Sprays	0.0	3	.186	.015	.136
	Time Since Spray	0.2	3	.171	< -.001	.387
	Null Model	0.2	2	.167	-	-
	Total Sprays + Time Since Spray	1.2	4	.1	< - .001 < - .001	.323
	Total Burns	1.4	3	.093	.006	.36
	Time Since Spray + Time Since Fire	2.2	4	.063	< -.001 < .001	.677
	Total Growing Season Burns	2.2	3	.062	.001	.912
	Time Since Fire	2.2	3	.061	< .001	.997
	Time Since Fire + Time Since Spray + Total Sprays	3.2	5	.037	<.001 < -.001 < -.001	.516
	Time Since Fire + Total Burns	3.3	4	.037	< .001 .007	.621
	Time Since Fire + Total Growing Season Burns	4.2	4	.023	< .001 < .001	.994
Forbs	Total Growing Season Burns	0.0	3	.396	.025	.335
	Time Since Fire + Total Growing Season Burns	2.0	4	.146	< .001 < .001	.108
	Null Model	2.5	2	.116	-	-
	Total Sprays	3.0	3	.087	.011	.234
	Total Burns	3.5	3	.068	- .005	.335
	Time Since Spray	4.0	3	.053	< -.001	.503
	Time Since Fire	4.5	3	.043	< -.001	.991
	Total Sprays + Time Since Spray	5.0	4	.033	.012 < .001	.482
	Time Since Fire + Total Burns	5.4	4	.027	< -.001 .007	.587
	Time Since Spray + Time Since Fire	3.0	4	.020	< -.001 < .001	.793
	Time Since Fire + Time Since Spray + Total Sprays	7.0	5	.012	.001 .001 .001	.69

Grasses	Time Since Spray + Time Since Fire	0.0	4	.559	< -.001 .002	<**.001**
	Time Since Fire + Time Since Spray + Total Sprays	1.3	5	.289	.001 < -.001 -.011	**.001**
	Time Since Spray	4.6	3	.056	< -.001	.006
	Time Since Fire + Total Growing Season Burns	5.8	4	.030	.001 .026	.016
	Total Sprays + Time Since Spray	6.0	4	.027	< .001 < -.001	.018
	Total Growing Season Burns	7.8	3	.011	.025	.066
	Time Since Fire	8.4	3	.008	< .001	.057
	Time Since Fire + Total Burns	8.5	4	.007	.001 .008	.064
	Null Model	10.1	2	.003	-	-
	Total Sprays	10.3	3	.003	.012	.18
	Total Burns	11.7	3	.001	.001	.546
Bare Ground	Time Since Fire	0.0	3	.33	-.002	<**.001**
	Time Since Fire + Total Burns	0.8	4	.22	-.002 -.005	<**.001**
	Time Since Spray + Time Since Fire	1.3	4	.17	< -.001 < -.001	<**.001**
	Time Since Fire + Time Since Spray + Total Sprays	1.5	5	.16	< -.001 < -.001 < -.001	<**.001**
	Time Since Spray + Total Growing Season Burns	2.0	4	.12	-.002 < -.001	<**.001**
	Null Model	19.1	2	<.001	-	-
	Total Sprays	20.1	3	<.001	.006	.334
	Total Burns	20.7	3	<.001	.003	.557
	Time Since Spray	21.0	3	<.001	< -.001	.887
	Total Growing Season Burns	21.1	3	<.001	< .001	.928
	Total Sprays + Time Since Spray	21.6	2	<.001	.011 < .001	.484

Total Selected Forb Cover	Total Growing Season Burns	0.0	3	.269	.019	.066
	Time Since Fire + Total Growing Season Burns	0.9	4	.171	< -.001 .019	.107
	Null Model	1.4	2	.135	-	-
	Time Since Fire	2.1	3	.092	< -.001	.268
	Time Since Spray	2.8	3	.067	< .001	.444
	Time Since Spray + Time Since Fire	3.1	4	.057	< .001 _< -.001	.328
	Total Burns	3.1	3	.056	-.002	.628
	Total Sprays	3.2	3	.055	-.003	.665
	Time Since Fire + Total Burns	3.3	4	.053	< -.001 .005	.351
	Total Sprays + Time Since Spray	4.8	4	.025	.001 < .001	.74
	Time Since Fire + Time Since Spray + Total Sprays	5.1	5	.021	< -.001 < .001 .001	.517
Total Selected Forb Richness	Total Sprays	0.0	3	.238	.246	**.041**
	Time Since Fire	1.1	3	.136	-.017	.081
	Time Since Fire + Time Since Spray + Total Sprays	1.7	5	.101	-.015 <.001 .238	.092
	Time Since Spray + Time Since Fire	1.8	4	.098	-.003 -.014	.112
	Time Since Spray	1.9	3	.090	-.003	.136
	Total Sprays + Time Since Spray	2.0	4	.088	.233 < -.001	.125
	Null Model	2.2	2	.080	-	-
	Time Since Fire + Total Growing Season Burns	3.1	4	.051	-.017 .037	.215
	Time Since Fire + Total Burns	3.1	4	.050	-.016 .004	.219
	Total Burns	3.7	3	.037	.054	.512
	Total Growing Season Burns	4.1	3	.031	.048	.77

Fabaceae	Total Sprays	0.0	3	.237	.015	**.024**
	Time Since Spray	0.1	3	.232	< -.001	**.025**
	Total Sprays + Time Since Spray	1.1	4	.136	.006 < -.001	.052
	Time Since Spray + Time Since Fire	1.2	4	.133	< -.001 < -.001	.053
	Time Since Fire + Time Since Spray + Total Sprays	2.2	5	.080	< -.001 < -.001 .006	.078
	Null Model	3.0	2	.052	-	-
	Time Since Fire	3.1	3	.050	< -.001	.167
	Total Growing Season Burns	4.8	3	.021	-.003	.664
	Time Since Fire + Total Growing Season Burns	4.9	4	.021	< -.001 -.003	.347
	Total Burns	5.0	3	.020	< .001	.787
	Time Since Fire + Total Burns	5.1	4	.019	< -.001 < -.001	.381
Asteraceae	Total Growing Season Burns	0.0	3	.283	.001	**.028**
	Time Since Spray	1.2	3	.157	< .001	.056
	Total Sprays	1.7	3	.121	-.013	.077
	Time Since Fire + Total Growing Season Burns	1.9	4	.110	< -.001 .022	.086
	Time Since Spray + Time Since Fire	2.5	4	.080	< .001 < -.001	.118
	Total Sprays + Time Since Spray	2.8	4	.070	-.006 < .001	.135
	Null Model	2.8	2	.069	-	-
	Time Since Fire + Time Since Spray + Total Sprays	4.2	5	.035	< -.001 < .001 -.006	.201
	Total Burns	4.4	3	.032	-.003	.51
	Time Since Fire	4.7	3	.027	< -.001	.695
	Time Since Fire + Total Burns	5.9	4	.015	< -.001 -.004	.381

Appendix C. Response variables and generalized linear models applied to them used to determine the effects of sericea lespedeza management on sericea and the native plant community over a 21-year observational study at the Joseph H. Williams Tallgrass Prairie Preserve. Includes results from AIC_c model ranking, analysis of variance (ANOVA) and the model summary.

VITA

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