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Analyzing the Effects of Winter-patch Grazing and Wildfire on Insect Order Hymenoptera in the Northern Great Plains

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ABSTRACT

Pollinators are declining globally, threatening global crop production and the biological integrity of many ecosystems. Hymenoptera (the order containing ants, bees, and wasps) is one of the most important insect orders for pollination of a variety of plants, including many crops, and is important as biocontrol for crop pests, and other herbivorous insects. Land management practices affect plant community composition, which influences vegetation-dependent insects, and consequently affects their ecosystem services. Fire and grazing are common practices on working landscapes in the Great Plains. However, how these management techniques impact insect diversity, particularly Hymenopterans, in a mixed-grass prairie ecosystem, is poorly understood. The objective of this study was to better understand how grazing practices affect Hymenopteran diversity. Sweep-net samples of insects were collected from three treatment sites on the mixed-grass prairie including wildfire paired with grazing (WF), winter-patch grazing (WPG), and season-long continuous grazing (CG, as a control). These samples were collected over two years, and each plot was sampled twice during each sampling year (totaling four sampling events). Specimens were then identified to family to better explain how land management practices affect diversity. Each treatment was statistically analyzed using single-factor ANOVA for abundance, family richness, evenness, and the Shannon-Wiener diversity

index. Ultimately, this study found that two- and three- years after the initial treatment, there were no differences in Hymenopteran abundance or diversity between pastures treated with WPG, or WF when compared to a CG control.

INTRODUCTION

Globally, insect populations are declining (Potts et al., 2010; Sánchez-Bayo & Wyckhuys, 2019; Thomas et al., 2019). Of all insect orders, Hymenoptera is speculated to contain the most species, and provides essential ecosystem services such as pollination, and biological control (Danforth, 2007; Forbes et al., 2018). It has been estimated that approximately 90% of all wild plant species require pollination by insects or other animals, but many agricultural plants also require pollination (Allen-Wardell et al., 1998; Klein et al., 2006; Ollerton et al., 2011; Ricketts et al., 2008). An estimated 35% of overall agricultural crop production by volume comes from pollinator-dependent crops (IPBES, 2016). This decline in insects is also concerning, as arthropods have long been recognized as environmental indicators, meaning that declines in their populations often act as early warning signs for changing environmental conditions (Kremen et al., 1993; Parikh et al., 2020). Bees and ants (order Hymenoptera) specifically have shown potential as effective indicator species (Orlofske et al., 2010; Williams et al., 2010). Thus, as insect populations steadily decline, we can hypothesize that entire ecosystems may also be suffering, and so we must pursue ways to ameliorate the damage being done before our global crop systems are affected and the damage incurred becomes irreversible.

Anthropogenic activities which alter ecosystem structures are one of the main contributing factors toward insect declines (Dicks et al., 2016; Sánchez-Bayo & Wyckhuys, 2019). The Northern Great Plains region has faced many significant alterations in the forms of large-scale monocultures (which decrease heterogeneity of the landscape) and altered disturbance regimes on remnant prairies (which lead to woody encroachment) (Benton et al., 2003; Symstad & Leis, 2017; van Auken, 2009). Diversity in the plant community has been shown to directly correlate to insect diversity (Benton et al., 2003; Pei et al., 2023). Historically, prairie ecosystems of the Northern Great Plains were maintained by natural fire and grazing disturbances (Collins, 1992; Fuhlendorf & Engle, 2004). However, prescribed burning has become a controversial management method across the United States as today many land managers, landowners, and ranchers, hesitate to use fire as a tool (Carle D, 2002; Ryan et al., 2013). When used improperly, fire can unpredictably consume large areas of land, thus inducing fear and unease (Clode & Elgar, 2014). Prescribed burning is also a very involved process as weather conditions must align properly to ensure safety and efficacy (Weir, 2011). Grasslands, however, require fire for proper maintenance. Not only does it prevent woody encroachment, but fire also promotes biodiversity, aids in nutrient cycling, and has been shown to suppress populations of invasive plant species (Ditomaso et al., 2006; Fuhlendorf & Engle, 2004; Goldas et al., 2022). Winter-patch grazing (WPG) has been proposed as an alternative to burn-grazing techniques and also increases heterogeneity within the plant community (Lutze, 2020; Zilverberg, 2019). As previously discussed, insect diversity is heavily reliant on the diversity in the plant community, suggesting that WPG would also improve insect heterogeneity, as burning does.

Some research suggests that grazing does not affect pollinators in the Great Plains, and that prescribed burning may have either no effect, or a positive effect (Bruninga-Socolar et al., 2022; Glenny et al., 2022). Other non-pollinating Hymenopterans, including parasitoid wasps, predatory wasps, and ants have been shown to follow similar trends in relation to fire disturbances where in some situations they are unaffected, and in others they benefit (Campbell et al., 2018; Mateos et al., 2011; Menke et al., 2015). Several factors have been shown to impact insect response to fire including the number of survivors and/or colonizers present to rebuild a population, post-treatment suitability of the vegetation for habitat (to satisfy nest building and dietary requirements), and level of stress experienced by individuals in the post-treatment environment (Swengel, 2001). These same factors may also relate to those impacting Hymenopteran response to other management practices such as grazing, mowing, or haying. Nesting preference may also impact post-disturbance survivorship. Most Hymenopterans in the Northern Great Plains tend to nest and/or overwinter underground, or in the stems of plants (Batra, 1964; Graham et al., 2020; Harper et al., 2000; Svensson et al., 2000). Depending on the fire dynamics, ground nesting species may potentially sustain fewer losses compared to species who utilize plant stems aboveground (Harper et al., 2000; Menke et al., 2015). Because some groups of Hymenopterans show an increase in abundance in response to disturbance events, while others remain the same, I expect to see a net increase in diversity and abundance in sites that were burned or treated with winter-patch grazing.

The goal of this study was to determine how Hymenopteran diversity is affected by winter-patch grazing or grazing paired with wildfire in comparison to a control treatment of continuous season-long grazing. The specific objective was to examine how alternative cattle grazing frameworks (winter-patch grazing and grazing paired with wildfire) affect

Hymenopteran family richness, evenness, abundance, and Shannon-Wiener diversity indices when compared to a continuous season-long grazing system. I expect that both the wildfire, and winter-patch grazing treatments will have greater Hymenopteran abundance, family richness, evenness, and Shannon-Wiener diversity indices than the continuous season-long grazing treatment.

METHODS

Study Site

The insect samples used for this study were collected at the SDSU Cottonwood Range and Livestock Field Station in Jackson County of western South Dakota near the town of Philip (43°53’37”N 101°45’). This site is a mixed-grass prairie ecosystem of the Northern Great Plains. Historically, the pastures at this site were grazed using a continuous season-long summer grazing regime.

Figure 1. Location of the SDSU Cottonwood Field Station in Jackson County of western South Dakota.

Experimental Design

Each pasture consisted of three different treatments. The first was a control treatment (with no new disturbance, maintaining the same historical, continuous season-long summer

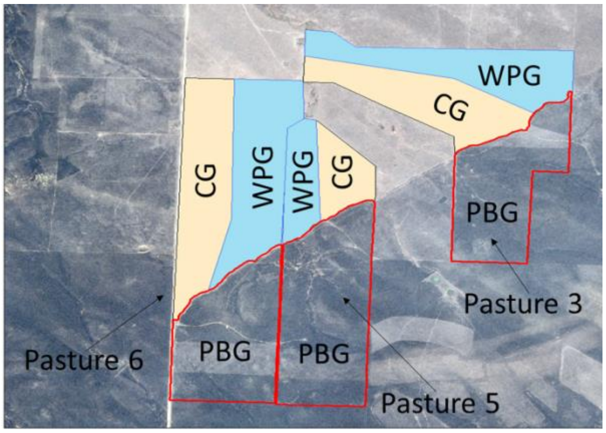

Figure 2. Map of study area (labeled by pasture and treatment) located at SDSU Cottonwood Field Station, Philip, SD.

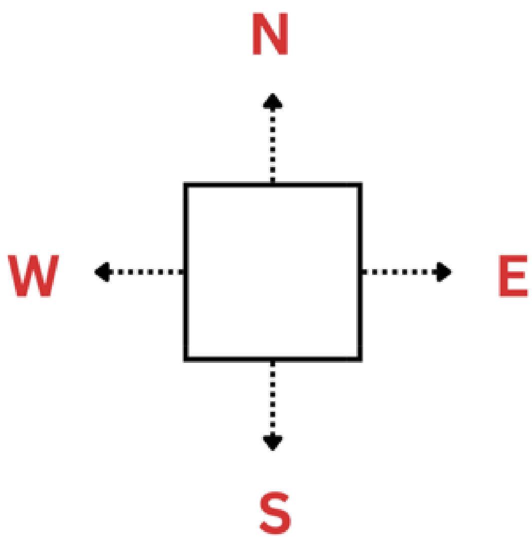

Figure 3. Visual of the sampling scheme used around an exclosure

Figure 4. Wing venation of bee belonging to the family Halictidae

grazing regime, which will be referred to as CG). The second treatment consisted of heavy winter grazing (which will be referred to as winter-patch grazing, or WPG). The third was a wildfire treatment (referred to as WF) that burned in October of 2016, and was subsequently grazed. Within each treatment, there were five exclosures (fenced off portions of the field that were not available to grazers) per pasture used for this study, totaling 15 exclosures per pasture, or 45 total exclosures.

Sampling Procedure and Data Collection

Four sampling events took place over two years (2018 and 2019). Each year, one sampling event occurred in June (referred to as 2018 event 1 and 2019 event 1), and one during August (referred to as 2018 event 2, and 2019 event 2). Netting samples were collected between 08:00 - 17:00 hours by travelling along transects following each of the four cardinal directions around an exclosure, beginning from the side of the fencing and adjusting to the cardinal direction (as displayed in Figure 3). Each transect measured 50 meters and consisted of 70 net strokes. Samples were then sorted by taxonomic order for each transect of an exclosure and stored in a freezer for preservation.

This study focuses on Hymenopterans from the sampling events of August 2018, June 2019, and August 2019, and omits the samples collected in June 2018. The omitted specimens were heavily degraded from time and improper storage, thus deeming identification efforts impractical. Using a dissecting microscope and a dichotomous key (Triplehorn & Johnson, 2005), the target specimens were identified to family (often using subtle diagnostic characteristics, such as wing venation, which is depicted in Figure 4).

Data Analysis

For each sampling event, one-way ANOVA testing was done by treatment and sampling event to test for significant differences in family richness, Shannon's H', Shannon's J' (evenness), and total insect abundance.

Family richness was calculated at the treatment level for each sampling event. This represents a count of the total number of insect families present.

Shannon's Diversity was calculated at the treatment level for each sampling event using the equation:

$$H' = \sum_{i=1}^{F} -(P_i * \ln P_i)$$

where F represents the number of families, P_i represents the proportion of individuals in the ith family, and ln represents the natural logarithm (Luz de la Maza et al., 2002; Shannon, 1948). This incorporates relative abundance and family richness, assuming that all families within the study area have been selected randomly (Luz de la Maza et al., 2002).

Shannon's evenness (J') was calculated at the treatment level for each sampling event using the equation:

$$J' = \frac{H'}{\ln(F)}$$

where H' represents family diversity, F represents family richness, and ln represents the natural logarithm. Evenness is a measure of the distribution of the relative abundance of families within a sample area (Shannon, 1948).

Rank abundance curves were also used to express family richness and evenness for each treatment and sampling event (Figures 13 - 18). The length of the curve represents richness (a longer curve indicates greater richness), and the slope of the curve represents evenness (a greater slope indicates lower evenness) (Magurran, 2013).

RESULTS

A total of 1,804 Hymenopterans from 21 families were collected between August 2018 and August 2019. There was only one exclosure where no Hymenopterans were found (which was in June of 2019). In sampling event two (August) of 2018 there were 422 Hymenopterans collected from 16 families, in sampling event one (June) of 2019 there were 411 Hymenopterans collected from 15 families, and in sampling event two (August) of 2019 there were 971

Hymenopterans collected from 19 families. Overall, the most abundant family recorded was Formicidae (the family containing all ants), with 801 individuals. There were four families of bees reported, one family of ants, and 16 families of wasps (14 of which were parasitoids).

Table 1 below summarizes the results for family richness, Shannon's diversity (H'), and Shannon's evenness (J') for each treatment and sampling event. These results were then tested against each other using one-way ANOVA to determine if there were significant differences among treatments or sampling events.

Table 1. Summary of mean Hymenopteran abundance, family richness, Shannon's diversity, and Shannon's evenness by treatment and sampling event

Treatment	Sampling Event	Mean Total Abundance	Mean Family Richness	Mean Shannon's Diversity	Mean Shannon's Evenness
CG	2018-2	49	13	1.76	68.59%
CG	2019-1	38.67	12	1.76	71.02%
CG	2019-2	96.33	13	1.76	68.54%
WPG	2018-2	49	11	1.54	64.37%
WPG	2019-1	48.67	14	1.79	67.93%
WPG	2019-2	97	18	1.78	61.53%
WF	2018-2	42.67	9	1.29	58.81%
WF	2019-1	49.67	10	1.69	73.46%
WF	2019-2	130.33	15	1.62	59.66%

In each of the sampling events, no significant difference was found between treatments for the family richness (Figure 5), Shannon's diversity (Figure 6), or total insect abundance (Figure 8). When Shannon's evenness was compared between treatments (Figure 7), the only significant difference found was between the CG and WF treatments of sampling event two in 2019. The WPG treatment for this sampling event was statistically similar to both the CG and WF treatments.

I also tested for significant differences within a treatment over time using one-way ANOVA. Across all treatments, there were no significant differences observed in family richness (Figure 9), Shannon's H' (diversity index) (Figure 10), or Shannon's J' (evenness index) (Figure 11) between sampling events. There were, however, significant differences found in abundance (Figure 12) between the second sampling event of 2019, and the other two previous sampling events, meaning that significantly more insects were collected during this event than were collected in any other event.

As a precursory way to begin analyzing my data, I created rank abundance curves based on sampling event and treatment. These curves (Figures 13 - 18) are a way to visualize family richness and evenness (Shannon's J'). However, it should be noted that the majority of these relationships were deemed statistically insignificant from each other in the statistics performed above, and thus, any potential differences observed are not statistically supported.

DISCUSSION

Heavy winter-patch grazing is a very new form of grazing that has not been researched in depth (Lutze, 2020; Weathers et al., 2018; Zilverberg, 2019). This is the first study to analyze Hymenopteran diversity from sites treated with winter-patch grazing. More research should be conducted to further test the benefits and limitations of using this type of grazing scheme as opposed to a burn-grazing scheme.

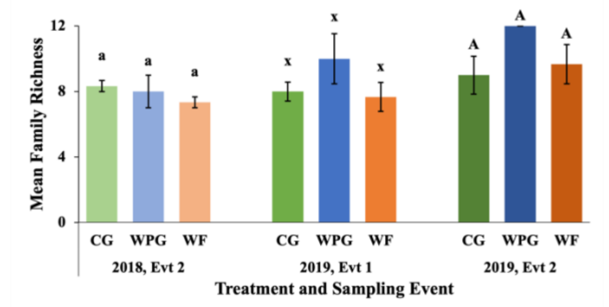

Figure 5. Mean family richness for each treatment and sampling event

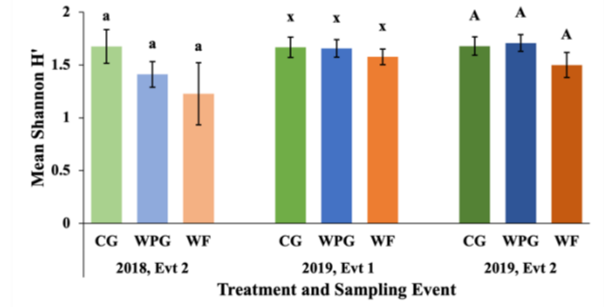

Figure 6. Mean Shannon's H' (diversity index) for each treatment and sampling event

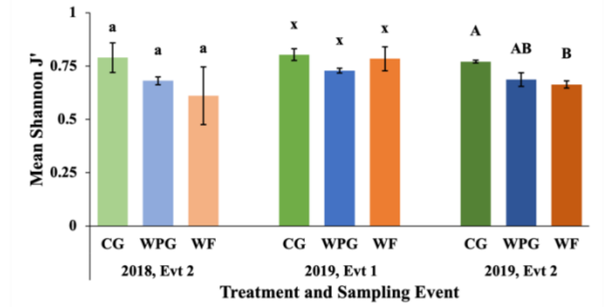

Figure 7. Mean Shannon's J' (evenness index) for each treatment and sampling event

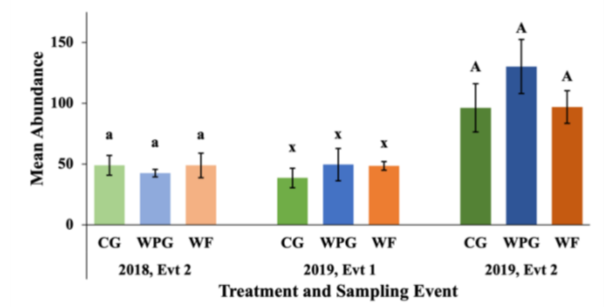

Figure 8. Mean abundance for each treatment and sampling event

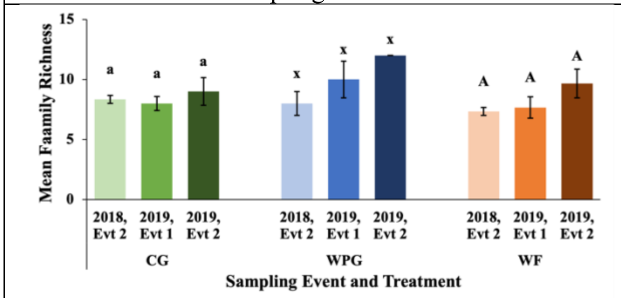

Figure 9. Mean family richness by treatment over time

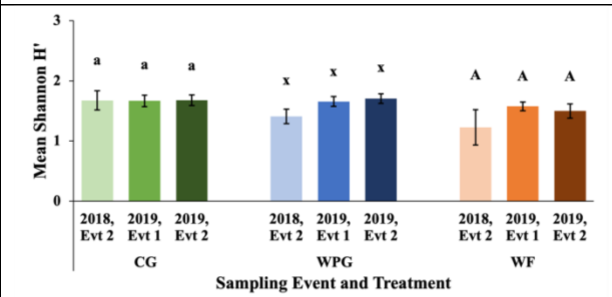

Figure 10. Mean Shannon's H' by treatment over time

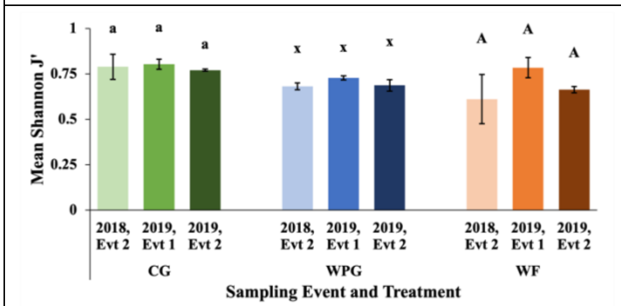

Figure 11. Mean Shannon's J' by treatment over time

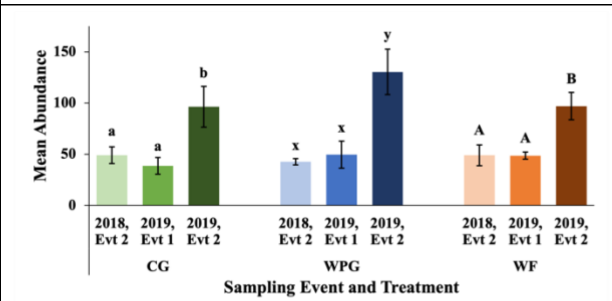

Figure 12. Mean abundance by treatment over time

CG = Continuous season-long grazing; WPG = Winter-patch grazing; WF = Wildfire; 2018, Evt 2 = Sampling event in Aug, roughly 2 years post-fire, 2019, Evt 1 = Sampling event in Jun, roughly 2.5 years post-fire, 2019, Evt 2 = Sampling event in Aug, roughly 3 years post-fire

Rank Abundance Compared Over Time	Rank Abundance Compared by Treatment

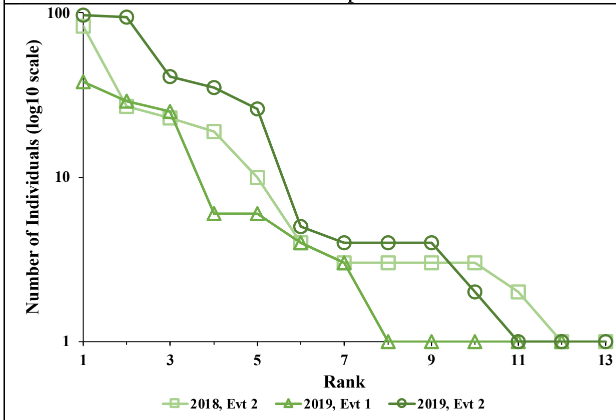

Figure 13. Family rank abundance of Continuous Season-Long Grazing (CG) treatment over time

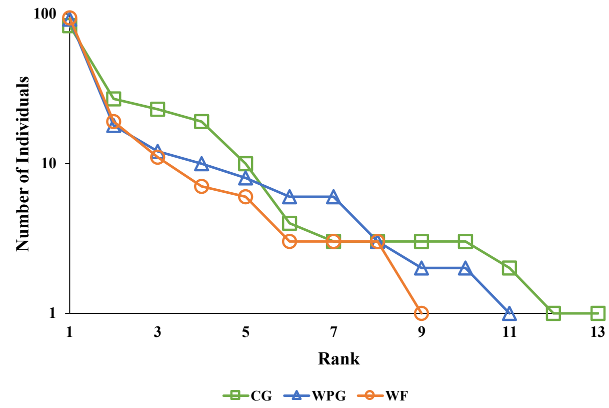

Figure 14. Family rank abundance of sampling event 2018, Evt 2 by treatment

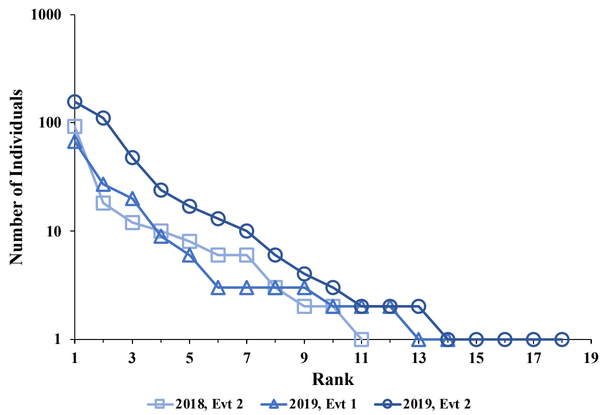

Figure 15. Family rank abundance of Winter-Patch Grazing (WPG) treatment over time

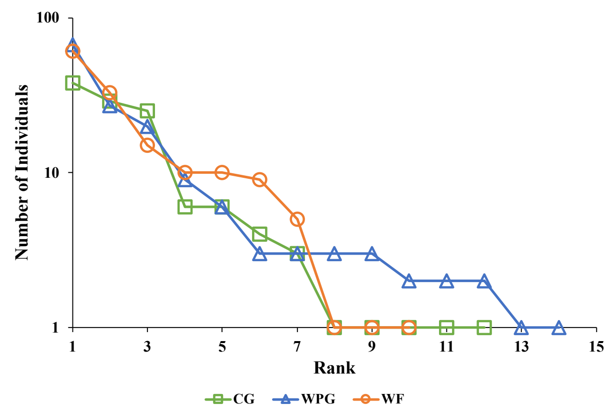

Figure 16. Family rank abundance of sampling event 2019, Evt 1 by Treatment

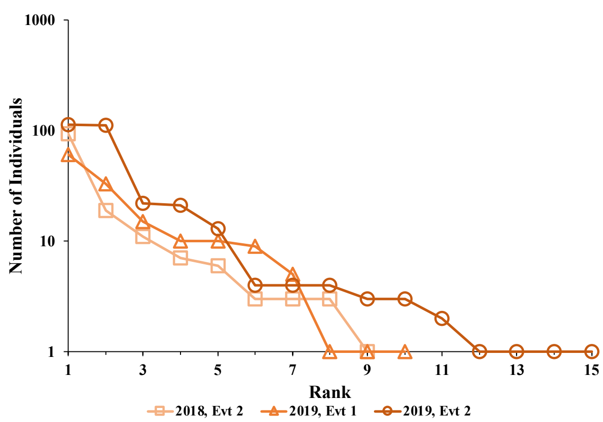

Figure 17. Family rank abundance of Wildfire (WF) treatment over time

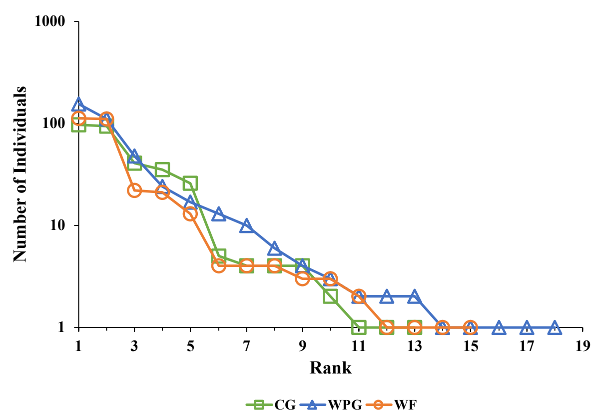

Figure 18. Family rank abundance of sampling event 2019, Evt 2 by treatment

2018, Evt 2 = Sampling event in Aug, roughly 2 years post-fire, 2019, Evt 1 = Sampling event in Jun, roughly 2.5 years post-fire, 2019, Evt 2 = Sampling event in Aug, roughly 3 years post-fire

Overall, the majority of my initial hypothesis was disproven as we found equal abundances, family richnesses, and Shannon's diversity index across all three treatments. This may be partially driven by having a large amount variation observed across a small number of data points, causing an inflated standard error. Had more pastures been tested (and thus more data points added to our analyses), we may have seen more relationships deemed significant. There was one significant difference found in 2019 event 2 when looking at the evenness between the CG and WF treatments, suggesting that burn-grazing may require longer than three years for Hymenopteran populations to be restored.

Hymenopteran Diversity Between Treatments

Ultimately, no significant trends were observed in Hymenopteran family diversity (Figure 5), Shannon's H' (diversity index) (Figure 6), or overall abundance (Figure 8) between grazing treatments. This may in part be because short term grazing treatments (lasting up to three years) do not always affect overall richness, but sites with extensive histories of grazing show significant differences in insect diversity, specifically in ants (Debinski et al., 2011). It is suggested that this could be caused by the perennial nature of ant colonies, which could create a longer lag time for any alterations in populations. Sites with long histories of grazing may also see soil compaction as an influencing factor affecting populations of ground nesting ants and bees (Debinski et al., 2011; Harmon-Threatt & Chin, 2016).

By the time that my samples were collected, the insect populations may also have had enough time to recover from their respective disturbance events. In cases of prescribed fire, arthropod species richness and Hymenopteran abundance have been observed to decrease one year post fire and rebound to the same level as nearby unburned sites by the third year (Andersen & Müller, 2000; Doxon et al., 2011; Swengel, 2001). Other research also suggests that, in the long-term, pollinator and other insect populations are unaffected by fire (Glenny et al., 2022; Swengel, 2001). As for the WPG treatment, some studies suggest that intensive grazing negatively affect the species richness of bees and wasps (Kruess & Tscharntke, 2002), while others suggest that these species are generally unaffected (Sjödin et al., 2008). More research should be done to conclude if heavy winter grazing significantly affects the diversity and abundance of Hymenopterans and other insects.

There was one significant result found for evenness between treatments. This occurred in 2019 event 2, (Figure 7) where we observed that the wildfire treatment (WF) had a significantly lower family evenness compared to the control (CG). The patch-burn-grazing treatment (PBG) proved to be statistically similar to both of these aforementioned treatments. Having greater evenness means that the site has greater heterogeneity as the observed families occur in more similar abundances, thus stabilizing the diversity (Alatalo, 1981; Jost, 2010). This suggests that the insect diversity found at the CG treatment site may be slightly more stable than the diversity found at the WF site three years post-fire. This could potentially mean that the insect populations of the WF site are still in the process of regenerating.

It is also important to note that even though differences in diversity were not detected on a family level, they could be detected on a species level. Research has shown that fire can affect insect species composition while not affecting an order’s overall abundance (Schlesinger et al., 1997). Total arthropod diversity may also remain the same post fire while species diversity is affected (York, 1999).

Hymenopteran Diversity Over Time Within a Treatment

I also looked at Hymenopteran diversity across time within a single treatment. It was concluded that for each of the three treatments there was no significant difference in family richness (Figure 9), Shannon's H' (Figure 10), or Shannon's J' (Figure 11). There was, however, greater abundance in 2019 sampling event two compared to the other sampling events (Figure 12). The difference observed between the late summer collections in 2018 and 2019 may be due to inherent sampling bias or having too few sampling sites. By late summer 2019, the collector would have been far more comfortable with the collection methods, and thus would have been able to obtain more insects. It is also possible that drier weather conditions in 2018 contributed to population declines. The field site where these insects were collected received 3.23 cm less precipitation than usual over that summer (South Dakota State University, 2023). Drier weather impacts the vegetative community and reduces the amount of forage available for herbivorous insects, thus increasing competition among insects for resources (Heisler-White et al., 2009; Lauenroth & Sala, 1992; Porensky et al., 2017). The discrepancy between June and August of 2019 could also be due to insect phenology, as some species are more prevalent in June than they are in August and vice versa (Novotny et al., 2021; Reed, 1995).

Directions for Future Research

The total number and variety of bees collected via sweep net seem to be a glaring underestimation of the total bee population of the collection site. We collected 453 bees, however, only 37 of these did not belong to the family Halictidae. Specifically, I expected to find many more representatives of the family Apidae (honeybees and bumblebees) as only 23 individuals were collected throughout this study. This may have been because, although sweep netting is an acceptable collection method for bees, it still has biases (Joshi et al., 2015; Prendergast et al., 2020). For future experiments, I would suggest using a variety of insect collection methods to reduce bias and provide a more complete picture of the insect diversity and abundance at the site. Blue-vane traps would help bolster bee representation and are one of the most effective methods for trapping bees (Joshi et al., 2015; Prendergast et al., 2020). One study compared the efficacy of blue-vane traps and sweep netting and found that blue-vane traps yielded twenty times more bees than sweep netting (Morandin et al., 2007). Implementing pitfall traps may also benefit future analyses to ensure a more complete representation of ant species present at the site (Lassau & Hochuli, 2004; Romero & Jaffe, 1989).

Another consideration is that this study looked at insect populations two- and three-years post-fire, however, insect populations are most heavily impacted by fire in the first year (Andersen & Müller, 2000; Doxon et al., 2011). More research should be conducted to determine how Hymenopterans and other insects are affected by winter-patch grazing in the first year after treatment to compare this result to that of burn-grazing techniques.

CONCLUSION

The results of this study suggest that two- and three-years post treatment, wildfire and winter-patch grazing treatments may not affect Hymenopteran populations when compared to continuous season-long grazing schemes. This implies that ranchers, landowners, and land managers could incorporate burning, or winter-patch grazing as management alternatives to increase the biodiversity of their land and may not need to worry about Hymenopteran populations being affected long term. This research can also be used by scientists to inform future research on the influence of grazing techniques on bees, wasps, and ants.

As insect populations continue to decline, it is vital to implement land management practices that will benefit insect populations and not aid in their demise (Dicks et al., 2016; Hanberry et al., 2021; Potts et al., 2010; Sánchez-Bayo & Wyckhuys, 2019). By implementing burn-grazing or winter-patch grazing techniques land managers can improve the state of their pastures for their cattle, and other wildlife without concern about long-term effects on pollinator populations (Buckley et al., 2022; Derner et al., 2009; Fuhlendorf & Engle, 2004; Lutze, 2020). This will help protect Hymenopterans, including pollinators and biological control agents, and safeguard the ecological services that they provide. Small steps toward restoring pollinator and other beneficial insect populations will set a trajectory of conservation that will benefit future generations.

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REFERENCES

Alatalo, R. v. (1981). Problems in the Measurement of Evenness in Ecology. *Oikos*, *37*(2), 199. https://doi.org/10.2307/3544465

Andersen, A. N., & Müller, W. J. (2000). Arthropod responses to experimental fire regimes in an Australian tropical savannah: ordinal-level analysis. *Austral Ecology*, *25*(2), 199–209. https://doi.org/https://doi.org/10.1046/j.1442-9993.2000.01038.x

Batra, S. W. (1964). Batra, Suzanne WT. "Behavior of the social bee, Lasioglossum zephyrum, within the nest (Hymenoptera: Halictidae). *Insectes Sociaux*, *11*(2), 159–185.

Benton, T. G., Vickery, J. A., & Wilson, J. D. (2003). Farmland biodiversity: is habitat heterogeneity the key? *TRENDS in Ecology and Evolution*, *18*(4), 182. https://doi.org/10.1016/S0169-5347(03)00011-9

Bruninga-Socolar, B., Griffin, S. R., Portman, Z. M., & Gibbs, J. (2022). Variation in prescribed fire and bison grazing supports multiple bee nesting groups in tallgrass prairie. *Restoration Ecology*, *30*(3), e13507. https://doi.org/https://doi.org/10.1111/rec.13507

Buckley, B. R., Lituma, C. M., Keyser, P. D., Holcomb, E. D., Smith, R., Morgan, J. J., & Applegate, R. D. (2022). Effects of grazing strategy on facultative grassland bird nesting on native grassland pastures of the Mid-South USA. *PeerJ*, *10*. https://doi.org/10.7717/PEERJ.13968

Campbell, J. W., Vigueira, P. A., Viguiera, C. C., & Greenberg, C. H. (2018). The Effects of Repeated Prescribed Fire and Thinning on Bees, Wasps, and Other Flower Visitors in the Understory and Midstory of a Temperate Forest in North Carolina. *Forest Science*, *64*(3), 299–306. https://doi.org/10.1093/forsci/fxx008

Carle D. (2002). *Burning Questions: America's Fight with Nature's Fire*. Greenwood Publishing Group. https://books.google.com/books?hl=en&lr=&id=23c5z7aco3gC&oi=fnd&pg=PP15&dq=controversy+of+prescribed+burns&ots=2mchIII7cA&sig=p_05RmknPihMKMn1usnpa2k1TsA#v=onepage&q=controversy%20of%20prescribed%20burns&f=false

Clode, D., & Elgar, M. A. (2014). Fighting Fire with Fire: Does a Policy of Broad-Scale Prescribed Burning Improve Community Safety? *Http://Dx.Doi.Org/10.1080/08941920.2014.905894*, *27*(11), 1192–1199. https://doi.org/10.1080/08941920.2014.905894

Collins, S. L. (1992). Fire frequency and community heterogeneity in tallgrass prairie vegetation. *Ecology*, *73*(6), 2001–2006. https://doi.org/10.2307/1941450

Danforth, B. (2007). Bees. *Current Biology*, *17*(5), R156–R161.

Debinski, D. M., Moranz, R. A., Delaney, J. T., Miller, J. R., Engle, D. M., Winkler, L. B., McGranahan, D. A., Barney, R. J., Trager, J. C., Stephenson, A. L., & Gillespie, M. K.

(2011). A cross-taxonomic comparison of insect responses to grassland management and land-use legacies. *Ecosphere*, *2*(12), art131. https://doi.org/https://doi.org/10.1890/ES11-00226.1

Derner, J. D., Lauenroth, W. K., Stapp, P., & Augustine, D. J. (2009). Livestock as ecosystem engineers for Grassland Bird habitat in the Western Great Plains of North America. *Rangeland Ecology and Management*, *62*(2), 111–118. https://doi.org/10.2111/08-008.1

Dicks, L. v., Viana, B., Bommarco, R., Brosi, B., Arizmendi, M. D. C., Cunningham, S. A., Galetto, L., Hill, R., Lopes, A. v., Pires, C., Taki, H., & Potts, S. G. (2016). Ten policies for pollinators. *Science*, *354*(6315), 975–976. https://doi.org/10.1126/SCIENCE.AAI9226/ASSET/0ED656BC-85B7-4372-833B-9B2017692A08/ASSETS/GRAPHIC/354_975_F2.JPEG

Ditomaso, J., Brooks, M., Allen, E., Minnich, R., Rice, P., & Kyser, G. (2006). Control of Invasive Weeds with Prescribed Burning. *Weed Technology - WEED TECHNOL*, *20*, 535–548. https://doi.org/10.1614/WT-05-086R1.1

Doxon, E. D., Davis, C. A., Fuhlendorf, S. D., & Winter, S. L. (2011). Aboveground Macroinvertebrate Diversity and Abundance in Sand Sagebrush Prairie Managed With the Use of Pyric Herbivory. *Rangeland Ecology & Management*, *64*(4), 394–403. https://doi.org/10.2111/REM-D-10-00169.1

Forbes, A. A., Bagley, R. K., Beer, M. A., Hippee, A. C., & Widmayer, H. A. (2018). Quantifying the unquantifiable: why Hymenoptera, not Coleoptera, is the most speciose animal order. *BMC Ecology*, *18*(1), 21. https://doi.org/10.1186/s12898-018-0176-x

Fuhlendorf, S. D., & Engle, D. M. (2004). Application of the fire-grazing interaction to restore a shifting mosaic on tallgrass prairie. *Journal of Applied Ecology*, *41*(4), 604–614. https://doi.org/10.1111/J.0021-8901.2004.00937.X

Glenny, W., Runyon, J. B., & Burkle, L. A. (2022). A review of management actions on insect pollinators on public lands in the United States. *Biodiversity and Conservation*, *31*(8), 1995–2016. https://doi.org/10.1007/s10531-022-02399-5

Goldas, C. da S., Podgaiski, L. R., da Silva, C. V. C., & Mendonça, M. D. S. (2022). Burning for grassland pollination: Recently burned patches promote plant flowering and insect pollinators. *Austral Ecology*, *47*(3), 491–506. https://doi.org/10.1111/AEC.13108

Graham, K. K., Perkins, J. A., Peake, A., Killewald, M., Zavalnitskaya, J., Wilson, J. K., & Isaacs, R. (2020). Wildflower plantings on fruit farms provide pollen resources and increase nesting by stem nesting bees. *Agricultural and Forest Entomology*, *432*(2), 222–231.

Hanberry, B. B., DeBano, S. J., Kaye, T. N., Rowland, M. M., Hartway, C. R., & Shorrock, D. (2021). Pollinators of the Great Plains: Disturbances, Stressors, Management, and Research Needs. *Rangeland Ecology & Management*, *78*, 220–234. https://doi.org/10.1016/J.RAMA.2020.08.006

Harmon-Threatt, A., & Chin, K. (2016). Common Methods for Tallgrass Prairie Restoration and Their Potential Effects on Bee Diversity. *Natural Areas Journal*, *36*(4), 400–411. https://doi.org/10.3375/043.036.0407

Harper, M. G., Dietrich, C. H., Larimore, R. L., & Tessene, P. A. (2000). Effects of prescribed fire on prairie arthropods: An enclosure study. *Natural Areas Journal*, *20*, 325–335. https://www.researchgate.net/publication/288306181_Effects_of_prescribed_fire_on_prairie_arthropods_An_enclosure_study

Heisler-White, J. L., Blair, J. M., Kelly, E. F., Harmoney, K., & Knapp, A. K. (2009). Contingent productivity responses to more extreme rainfall regimes across a grassland biome. *Global Change Biology*, *15*(12), 2894–2904. https://doi.org/10.1111/J.1365-2486.2009.01961.X

IPBES. (2016). *The assessment report of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services on pollinators, pollination and food production*. https://doi.org/10.5281/ZENODO.3402857

Joshi, N. K., Leslie, T., Rajotte, E. G., Kammerer, M. A., Otieno, M., & Biddinger, D. J. (2015). Comparative Trapping Efficiency to Characterize Bee Abundance, Diversity, and Community Composition in Apple Orchards. *Annals of the Entomological Society of America*, *108*(5), 785–799. https://doi.org/10.1093/AESA/SAV057

Jost, L. (2010). The Relation between Evenness and Diversity. *Diversity 2010, Vol. 2, Pages 207-232*, *2*(2), 207–232. https://doi.org/10.3390/D2020207

Klein, A. M., Vaissière, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., & Tscharntke, T. (2006). Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B: Biological Sciences*, *274*(1608), 303–313. https://doi.org/10.1098/RSPB.2006.3721

Lassau, S. A., & Hochuli, D. F. (2004). Effects of habitat complexity on ant assemblages. *Ecography*, *27*(2), 157–164. https://doi.org/10.1111/J.0906-7590.2004.03675.X

Lauenroth, W. K., & Sala, O. E. (1992). Long-Term Forage Production of North American Shortgrass Steppe. *Ecological Applications*, *2*(4), 397–403. https://doi.org/10.2307/1941874

Lutze, J. (2020). *Winter Patch Grazing, Patch Burn Grazing, and Bird Communities in Western South Dakota* [Electronic Theses and Dissertations]. South Dakota State University.

Luz de la Maza, C., Hernández, J., Bown, H., Rodríguez, M., & Escobedo, F. (2002). VEGETATION DIVERSITY IN THE SANTIAGO DE CHILE URBAN ECOSYSTEM. *Arboricultural Journal*, *26*(4), 347–357. https://doi.org/10.1080/03071375.2002.9747349

Magurran, A. E. (2013). *Measuring Biological Diversity*. John Wiley & Sons.

Mateos, E., Santos, X., & Pujade-Villar, J. (2011). Taxonomic and Functional Responses to Fire and Post-Fire Management of a Mediterranean Hymenoptera Community. *Environmental Management*, *48*(5), 1000. https://doi.org/10.1007/s00267-011-9750-0

Menke, S. B., Gaulke, E., Hamel, A., & Vachter, N. (2015). The Effects of Restoration Age and Prescribed Burns on Grassland Ant Community Structure. *Environmental Entomology*, *44*(5), 1336–1347. https://doi.org/10.1093/ee/nvv110

Morandin, L. A., Winston, M. L., Abbott, V. A., & Franklin, M. T. (2007). Can pastureland increase wild bee abundance in agriculturally intense areas? *Basic and Applied Ecology*, *8*(2), 117–124. https://doi.org/https://doi.org/10.1016/j.baae.2006.06.003

Novotny, J. L., Reeher, P., Varvaro, M., Lybbert, A., Smith, J., Mitchell, R. J., & Goodell, K. (2021). Bumble bee species distributions and habitat associations in the Midwestern USA, a region of declining diversity. *Biodiversity and Conservation*, *30*(3), 865–887. https://doi.org/10.1007/S10531-021-02121-X/FIGURES/5

Ollerton, J., Winfree, R., & Tarrant, S. (2011). How many flowering plants are pollinated by animals? *Oikos*, *120*(3), 321–326. https://doi.org/10.1111/J.1600-0706.2010.18644.X

Orlofske, J., Ohnesorg, W., & Debinski, D. (2010). Potential Terrestrial Arthropod Indicators for Tallgrass Prairie Restoration in Iowa. *Ecological Restoration*, *28*, 250–253. https://doi.org/10.1353/ecr.2010.0013

Parikh, G., Rawtani, D., & Khatri, N. (2020). “Insects as an Indicator for Environmental Pollution.” *Https://Doi.Org/10.1080/10406026.2020.1780698*, *33*(2), 161–181. https://doi.org/10.1080/10406026.2020.1780698

Pei, C. K., Hovick, T. J., Limb, R. F., Harmon, J. P., & Geaumont, B. A. (2023). Invasive grass and litter accumulation constrain bee and plant diversity in altered grasslands. *Global Ecology and Conservation*, *41*. https://doi.org/10.1016/J.GECCO.2022.E02352

Porensky, L. M., Derner, J. D., Augustine, D. J., & Milchunas, D. G. (2017). Plant Community Composition After 75 Yr of Sustained Grazing Intensity Treatments in Shortgrass Steppe. *Rangeland Ecology & Management*, *70*(4), 456–464. https://doi.org/10.1016/J.RAMA.2016.12.001

Potts, S. G., Biesmeijer, J. C., Kremen, C., Neumann, P., Schweiger, O., & Kunin, W. E. (2010). Global pollinator declines: trends, impacts and drivers. *Trends in Ecology & Evolution*, *25*(6), 345–353. https://doi.org/10.1016/j.tree.2010.01.007

Prendergast, K. S., Menz, M. H. M., Dixon, K. W., & Bateman, P. W. (2020). The relative performance of sampling methods for native bees: an empirical test and review of the literature. *Ecosphere*, *11*(5), e03076. https://doi.org/https://doi.org/10.1002/ecs2.3076

Reed, C. (1995). Species richness of insects on prairie flowers in southeastern Minnesota. *Proceedings of the 14th Annual North American Prairie Conference*, 103–105.

Romero, H., & Jaffe, K. (1989). A Comparison of Methods for Sampling Ants (Hymenoptera, Formicidae) in Savannas. *Biotropica*, *21*(4), 348–352. https://doi.org/10.2307/2388285

Ryan, K. C., Knapp, E. E., & Varner, J. M. (2013). Prescribed fire in North American forests and woodlands: history, current practice, and challenges. *Frontiers in Ecology and the Environment*, *11*(s1), e15–e24. https://doi.org/10.1890/120329

Sánchez-Bayo, F., & Wyckhuys, K. A. G. (2019). *Worldwide decline of the entomofauna: A review of its drivers*. https://doi.org/10.1016/j.biocon.2019.01.020

Schlesinger, C., Noble, J., & Weir, T. (1997). Fire studies in mallee (Eucalyptus spp.) communities of western New South Wales: reptile and beetle populations in sites of differing fire history. *The Rangeland Journal*, *19*(2), 190–205.

Shannon, C. E. (1948). A Mathematical Theory of Communication. *Bell System Technical Journal*, *27*(3), 379–423. https://doi.org/https://doi.org/10.1002/j.1538-7305.1948.tb01338.x

South Dakota State University. (2023). South Dakota Mesonet. In *South Dakota Mesonet Database*.

Svensson, B., Lagerlöf, J., & G. Svensson, B. (2000). Habitat preferences of nest-seeking bumble bees (Hymenoptera: Apidae) in an agricultural landscape. *Agriculture, Ecosystems & Environment*, *77*(3), 247–255. https://doi.org/https://doi.org/10.1016/S0167-8809(99)00106-1

Swengel, A. B. (2001). A literature review of insect responses to fire, compared to other conservation managements of open habitat. *Biodiversity & Conservation*, *10*(7), 1141–1169. https://doi.org/10.1023/A:1016683807033

Symstad, A. J., & Leis, S. A. (2017). Natural Areas Association Woody Encroachment in Northern Great Plains Grasslands. *Source: Natural Areas Journal*, *37*(1), 118–127. https://doi.org/10.2307/90009260

Thomas, C. D., Jones, T. H., & Hartley, S. E. (2019). “Insectageddon”: A call for more robust data and rigorous analyses. *Global Change Biology*, *25*(6), 1891–1892. https://doi.org/10.1111/GCB.14608

van Auken, O. W. (2009). Causes and consequences of woody plant encroachment into western North American grasslands. *Journal of Environmental Management*, *90*(10), 2931–2942. https://doi.org/10.1016/J.JENVMAN.2009.04.023

Weir, J. R. (2011). Are Weather and Tradition Reducing Our Ability to Conduct Prescribed Burns? *Https://Doi.Org/10.2111/RANGELANDS-D-10-00050.1*, *33*(1), 25–30. https://doi.org/10.2111/RANGELANDS-D-10-00050.1

Williams, N. M., Crone, E. E., Roulston, T. H., Minckley, R. L., Packer, L., & Potts, S. G. (2010). Ecological and life-history traits predict bee species responses to environmental disturbances. *Biological Conservation*, *143*(10), 2280–2291. https://doi.org/10.1016/J.BIOCON.2010.03.024

York, A. (1999). Long-term effects of repeated prescribed burning on forest invertebrates: management implications for the conservation of biodiversity. *Australia's Biodiversity – Responses to Fire. Plants, Birds and Invertebrates*, 181–266.

Zilverberg, L. W. (2019). *The Tortoise (Wildfire) and the Hare (Heavy Winter Grazing) for Promoting Heterogeneity and Improving Ecosystem Services* [Electronic Theses and Dissertations, South Dakota State University]. https://openprairie.sdstate.edu/etd/3633