

Effects of prescribed fire and mechanical thinning on oak regeneration and white-tailed deer
activity in a Kansas woodland

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Abstract

Transformation from desirable to undesirable tree species is an issue concerning woodland managers across the United States. Forests, woodlands, and tree cover occupy 5.2 million acres in Kansas, representing 10 percent of the total land area. Oak (*Quercus spp.*) woodlands are common across eastern Kansas and are transitioning from shade intolerant to shade tolerant species, such as hackberry (*Celtis occidentalis*), American elm (*Ulmus americana*), Eastern redcedar (*Juniperus virginiana*), and redbud (*Cercis canadensis*). A 10-year repeated measures study was conducted from 2014 to 2023 on a 90-acre tract dominated by chinkapin oak near Manhattan, Kansas to determine the effects of repeated prescribed fire and mechanical thinning in an oak woodland on woody vegetation. In addition, White-tailed deer activity was monitored from July 2022 to January 2024 to understand deer activity within forestry treatments. Our results indicated Burn Only and Thin Only had the greatest increase in oak seedlings during the duration of the study period. Competitor species were most abundant in the Burn and Thin areas at the conclusion of our study. Deer activity was highest in Burn Only and Control areas during our study period, but activity shifted to Burn Only and Burn and Thin areas during the Fawn Rearing and Antler Growing season for does, indicating does are using areas during this season that were managed with prescribed fire. Undesired, shade tolerant species will continue to dominate the seedling stage without proper management, and periodic fires can be effective for improving deer habitat in hardwood systems.

Table of Contents

List of Figures	vi
List of Tables	xi
Acknowledgements	xii
Dedication	xiii
Chapter 1 - Long term effects of prescribed fire to encourage oak regeneration	1
Abstract	2
Introduction.....	3
Methods	6
Study Site and Experimental Design	6
Data Collection	8
Treatments.....	9
Data Processing and Statistical Analysis	10
Results.....	11
Seedlings	11
Saplings.....	13
Mature Trees Per Acre	14
Mature Tree Basal Area	15
Fuel Load Recovery	15
Discussion	16
References.....	20
Chapter 2 - White-tailed deer responses to prescribed fire and thinning in a Kansas woodland.	40
Abstract	41
Introduction.....	42
Methods	46
Study Area	46
Experimental Design.....	46
Treatments.....	47
Habitat Use and Photo Processing	48
Data Analysis	49

Results.....	50
All Deer.....	50
Does	51
Bucks.....	51
Fawns	51
Discussion.....	52
References.....	56
Appendix A - Oak Regeneration Pictures.....	69
Appendix B - White-tailed deer activity	86

List of Figures

Figure 1.1. Experimental layout with four treatments, and three replicates of each treatment; “Control” (C) “Thin Only” (T), “Burn Only” (B), and “Burn and Thin Combined” (BT). In total, 91 permanent data collection points were established throughout the study area. Burns and thinnings occurred in 2015 and 2018.	28
Figure 1.2. Permanent data collection point (plot centers) structure for seedlings, saplings and mature trees.	29
Figure 1.3. FIREMON sampling plane layout (1 transect) for the fuel load estimation (Lutes et al. 2006).	29
Figure 1.4. Stocking chart for measuring and evaluating stand density in upland hardwood forest in Central United States using basal area per acre, average trees per acre, and average tree diameter. The area between the A and B curve indicates the range of stocking where trees can fully utilize the growing space. The diameter of trees range between 7-15in. Curve C shows the lower limit of stocking necessary to reach the B level in 10 years on average sites (Gingrich, S.F. 1967).	30
Figure 1.5. Group means comparison of seedlings per acre of years averaged from 2020-2023 at the Howe Natural Resources Education Center, Manhattan, Kansas. Treatments are burn only, burn and thin, control, and thin only, treatments occurred in 2015 and 2018. Species groups are oaks (chinkapin oak, bur oak, black oak), walnut & hickory, primary competitors (Eastern redcedar, hackberry, American elm), redbud, and others (Kentucky coffeetree, red mulberry, honey locust, green ash). Bars sharing letters above confidence intervals indicate significance.	31
Figure 1.6. Group means comparison of oak seedlings per acre from pre-treatment 2014 and post-treatment 2023 at the Howe Natural Resources Education Center, Manhattan, Kansas. Oaks consist of chinkipin oak, black oak, and bur oak. Treatments are burn only, burn and thin, control, and thin only, treatments occurred in 2015 and 2018. Bars sharing letters above confidence intervals indicate significance.	32
Figure 1.7. Group means comparison of saplings per acre of years averaged from 2020-2023 at the Howe Natural Resources Education Center, Manhattan, Kansas. Treatments are burn only, burn and thin, control, and thin only, treatments occurred in 2015 and 2018. Species	

groups are oaks (chinkapin oak, bur oak, black oak), walnut & hickory, primary competitors (Eastern redcedar, hackberry, American elm), redbud, and others (Kentucky coffeetree, red mulberry, honey locust, green ash). Bars sharing letters above confidence intervals indicate significance.	33
Figure 1.8. Group means comparison of oak saplings per acre from pre-treatment 2014 and post-treatment 2023 at the Howe Natural Resources Education Center, Manhattan, Kansas. Treatments are burn only, burn and thin, control, and thin only, treatments occurred in 2015 and 2018.....	34
Figure 1.9. Group means comparison of trees per acre of years averaged from 2020-2023 at the Howe Natural Resources Education Center, Manhattan, Kansas. Treatments are burn only, burn and thin, control, and thin only, treatments occurred in 2015 and 2018. Species groups are oaks (chinkapin oak, bur oak, black oak), walnut & hickory, primary competitors (Eastern redcedar, hackberry, American elm), redbud, and others (Kentucky coffeetree, red mulberry, honey locust, green ash). Bars sharing letters above confidence intervals indicate significance.	35
Figure 1.10. Grouped bar chart showing basal area (left) and trees per acre (right) for oaks (chinkapin oak, bur oak, black oak) from pre-treatment (2014) to post-treatment (2023) after two burns and two thinnings at Howe Natural Resources Education Center, Manhattan, Kansas. Treatments occurred in 2015 and 2018, (B) Burn Only, (BT) Burn and Thin, (C) Control, (T) Thin Only.....	36
Figure 1.11. Bar graph comparing total duff consumption and recovery from two prescribed burns at Howe Natural Resources Education Center, Manhattan, Kansas. Prescribed burns occurred in 2015 and 2018, there was not a burn from 2018 to 2023. Values are combined means from burn only and burn and thin areas. Asterisks above error bars indicate significance within year.	37
Figure 1.12. Bar graph comparing total litter consumption and recovery from two prescribed burns at Howe Natural Resources Education Center, Manhattan, Kansas. Prescribed burns occurred in 2015 and 2018, there was not a burn from 2018 to 2023. Values are combined means from burn only and burn and thin areas. Asterisks above error bars indicate significance within year.	38

Figure 1.13. Bar graph comparing total fuel load consumption and recovery from two prescribed burns at Howe Natural Resources Education Center, Manhattan, Kansas. Prescribed burns occurred in 2015 and 2018, there was not a burn from 2018 to 2023. Values are combined means from burn only and burn and thin areas. Asterisks above error bars indicate significance within year.	39
Figure 2.1. Experimental layout of study site showing camera trap locations (red dots) and forestry treatments at Howe Natural Resources Education Center, Manhattan, Kansas, United States. Treatments include “Burn Only” (B), “Thin Only” (T), “Burn and Thin” (BT), and “Control” (C). Plots range between 6-10 acres, and treatment occurred in 2015 ad 2018. In total, 24 camera traps were places throughout the study area (red dots).	64
Figure 2.2. Additive model bar graph for weekly photographic rate of White-tailed deer within forestry treatments (left) at Howe Natural Resources Education Center and biological season (right) (winter: January 1 – March 14, winter-spring: March 15 – May 14, Fawning: May 15 – August 30, breeding: September 1 – December 31) in Kansas, United States, from July 2022 to January 2024. Comparisons are made between treatments and between seasons.	65
Figure 2.3. Two-way interactive model of weekly photographic rate of doe White-tailed deer within forestry treatments and biological season (winter: January 1 – March 14, winter-spring: March 15 – May 14, Fawning: May 15 – August 30, breeding: September 1 – December 31) at Howe Natural Resources Education Center, Kansas, United States, from July 2022 to January 2024.	66
Figure 2.4. Additive model bar graph for weekly photographic rate of buck White-tailed deer within forestry treatments (left) at Howe Natural Resources Education Center and biological season (right) (winter: January 1 – March 14, winter-spring: March 15 – May 14, Fawning: May 15 – August 30, breeding: September 1 – December 31) in Kansas, United States, from July 2022 to January 2024. Comparisons are made between treatments and between seasons.	67
Figure 2.5. Additive model bar graph for weekly photographic rate of fawn White-tailed deer within forestry treatments (left) at Howe Natural Resources Education Center and biological season (right) (winter: January 1 – March 14, winter-spring: March 15 – May 14, Fawning: May 15 – August 30, breeding: September 1 – December 31) in Kansas, United States,	

from July 2022 to January 2024. Comparisons are made between treatments and between seasons.	68
Appendix Figure A.1. Study area location of Howe Natural Resources Education Center in Riley County, Kansas. Red square indicates 145-acre study area location. The study area is divided into 12 compartments each assigned a treatment. Burn only, thin only, burn and thin, and control. There are three replicates of each treatment, totaling 12 compartments. .	69
Appendix Figure A.2. Sign located at Howe Natural Resources Education Center. Picture taken by Pahodha Galgamuwa.	70
Appendix Figure A.3. Part of the Howe Natural Resources Education Center project was funded by the National Wild Turkey Federation (NWTF) funds. Prescribed burns were organized by the Kansas Forest Service. Picture taken by Pabodha Galgamuwa.	71
Appendix Figure A.4. Tree girdled and treated with Garlon and diesel mixture during thinning operations at the Howe Natural Resources Education Center, Manhattan, Kansas. Thinning was prescribed to remove 25 trees per acre of Eastern redcedar (<i>Juniperus virginiana</i>), American elm (<i>Ulmus americana</i>), hackberry (<i>Celtis occidentalis</i>), and Eastern redbud (<i>Cecis Canadensis</i>); and 50 sapling per acre of Eastern redcedar, American elm, hackberry and Eastern redbud. Photo taken by Pabodha Galgamuwa. 50 stems of saplings/acre of American elm, Eastern redbud, Eastern redcedar and hackberry	72
Appendix Figure A.5. Smaller saplings were felled and treated with Garlon and diesel mixture. Photo taken by Pabodha Galgamuwa.....	73
Appendix Figure A.6. Fire behavior of the 2015 burn near a data collection point (T post). Photo by Pabodha Galgamuwa.	74
Appendix Figure A.7. Low intensity fire behavior of the 2015 burn. Photo by Pabodha Galgamuwa.	75
Appendix Figure A.8. Tall flames in a burned and thinned area in 2015. Photo by Pabodha Galgamuwa.	76
Appendix Figure A.9. Kansas Forest Service firefighter in a burned and thinned area in 2015. Flames were up to 20 feet tall on thinned Eastern redcedars. Photo by Pabodha Galgamuwa.	77

Appendix Figure A.10. Burns were successful at consuming the fuel in 2015. Photo by Pabodha Galgamuwa.	78
Appendix Figure A.11. Chinkapin oak (left) and Eastern redbud (right) sprouting after being top killed during a burn. Photo by Pabodha Galgamuwa.	79
Appendix Figure A.12. Burn attempt in May 2023. The vegetation was green, and the fuel load was too wet.	80
Appendix Figure A.13. May 2023 burn attempt.	81
Appendix Figure A.14. Measuring dead woody debris diameter in a thinned area for fuel load.	82
Appendix Figure A.15. Measuring litter depth.	83
Appendix Figure A.16. Collecting seedling data at data collection point.	84
Appendix Figure A.17. Identifying seedling species at data collection point.	85
Appendix Figure B.1. Changing SD cards and batteries on a on a two-week rotation for camera traps.	86
Appendix Figure B.2. Camera setup 0.5 meters off the ground in a Burn Only area near a preexisting t-post.	87
Appendix Figure B.3. Camera near highly palatable wild raspberries in a burn and thin area. ...	88
Appendix Figure B.4. Deer rub on a small tree in a burn and thin area.	89
Appendix Figure B.5. Deer browse on the lower leaves of a chinkapin oak sapling.	90
Appendix Figure B.6. Deer photos from Howe Natural Resource Education Center.	91
Appendix Figure B.7. First time gathering cameras data in July 2022.	92

List of Tables

Table 1.1. Mean seedlings per acre from 2020 to 2022 at the Howe Natural Resources Education Center, Manhattan, Kansas.	27
Table 1.2. Mean saplings per acre from 2020 to 2022 at the Howe Natural Resources Education Center, Manhattan, Kansas.	27
Table 1.3. Trees per acre and basal area means from 2014 to 2023 at the Howe Natural Resources Education Center, Manhattan, Kansas.....	27
Table 2.1. Candidate models and model statistics for all-deer category of White-tailed deer activity at Howe Natural Resource Center, Kansas, United States, from July 2022 to January 2024. Forestry treatments included burn only, thin only, burn and thin, and control. Seasons were: (winter: January 1 – March 14, winter-spring: March 15 – May 14, Fawning: May 15 – August 30, breeding: September 1 – December 31).	62
Table 2.2. Candidate models and model statistics for does category of White-tailed deer activity at Howe Natural Resources Education Center, Kansas, United States, from July 2022 to January 2024. Forestry treatments included burn only, thin only, burn and thin, and control. Seasons were: (winter: January 1 – March 14, winter-spring: March 15 – May 14, Fawning: May 15 – August 30, breeding: September 1 – December 31).....	62
Table 2.3. Candidate models and model statistics for does category of bucks White-tailed deer activity at Howe Natural Resources Education Center, Kansas, United States, from July 2022 to January 2024. Forestry treatments included burn only, thin only, burn and thin, and control. Seasons were: (winter: January 1 – March 14, winter-spring: March 15 – May 14, Fawning: May 15 – August 30, breeding: September 1 – December 31).....	62
Table 2.4. Candidate models and model statistics for fawns category of White-tailed deer activity at Howe Natural Resources Education Center, Kansas, United States, from July 2022 to January 2024. Forestry treatments included burn only, thin only, burn and thin, and control. Seasons were: (winter: January 1 – March 14, winter-spring: March 15 – May 14, Fawning: May 15 – August 30, breeding: September 1 – December 31).....	63

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Dedication

To my dad, Dan Wurtz, for teaching me about creation, and aiding in my relationship with the creator. To my mom, Donna Gebhardt for believing in me and her support. My siblings, Kameron, Wyatt, Macie, Payton, and Caleb for the countless laughs and fellowship.

Chapter 1 - Long term effects of prescribed fire to encourage oak regeneration

Abstract

Woodland managers across the United States are faced with shifts in composition from desirable to undesirable tree species. Forests, woodlands, and tree cover occupy 5.2 million acres in Kansas representing 10 percent of the total land area. Oak (*Quercus* spp.) woodlands are common across eastern Kansas, but regeneration in these stands is dominated by lower value shade tolerant species. A repeated measures study was conducted from 2014 to 2022 on a 90-acre oak dominated woodland near Manhattan, Kansas to determine the effects of prescribed fire and mechanical thinning on oak regeneration. Thinning reduced overall trees per acre, but when not followed by fire, Eastern redbud and Eastern redcedar increased. When we assessed seedling responses, Burn Only and Thin Only treatments resulted in the highest mean oak seedling recruitment since 2014, but there was not a significant difference. Oak saplings were more abundant in the Control and Burn Only areas, and there was not a difference in oak saplings from 2014 to 2023 within treatments. Thinning was effective at reducing competitor trees per acre, and oak trees were more abundant than the competitor species in the Burn Only, Thin Only, and Burn and Thin areas. We recommend using low intensity fires and canopy openings to recruit oak seedlings while reducing competing species.

Introduction

Natural disturbances in forested ecosystems can directly influence biodiversity (Swanson et al. 2011, Lindenmayer et al. 2019). Plant structure and community composition are greatly influenced by disturbances which can affect the temporal and spatial patterns of forested landscapes. Moreover, flora and fauna have developed characteristics to withstand these disturbances and that have influenced evolutionary strategies for plants (Grime 2006, Gutshick and Bassirirad 2003). Fires, drought events, canopy reductions, and insect outbreaks are examples of natural disturbances that occur in a wide variety of ecosystems. Disturbances are often used as management practices because of changes in the biotic and abiotic community they cause in many ecosystems.

Historically, native Americans used fire for diverse purposes, ranging from cultivation of plants for food, to the extensive modification of landscapes for game management or travel (Pyne 2017, Abrams and Nowacki 2008). In the early 1900s fire was viewed as destructive to wildlife habitat, and fear of uncontrolled wildfires kept land managers from burning. Views of prescribed fire from land managers have changed over time, and recently have pivoted toward promotion of fire as an effective management tool in oak (*Quercus*) forest management (Dey et al. 2022). Fire has been slowly becoming more accepted as a management tool since the 1960s (Dey et al. 2022), and now prescribed fire is used by several federal land management agencies, including the USDA Forest Service [1905], USDI National Park Service [1916], and the Bureau of Land Management [1946] as well as state natural resource agencies and non-governmental organizations (Pyne 1982).

Oaks have adapted fire tolerant characteristics including thick bark, ability to resprout after a fire, and capability to heal from fire scars (Arthur et al. 2012), as well as a developing a

deep taproot during the seedling stage which makes them competitive in most timber stands that are periodically burned (Choung 2004). Previous research shows low intensity surface fires were crucial to the development of oak-hickory forests (Abrams 1992), but their sustainability is threatened due to poor regeneration. A large portion of oak-hickory hardwood stands are transitioning to shade tolerant species (Abrams 2003) because of the ability of shade tolerant species to grow well in the dense shade produced by a closed canopy (Lorimer 1984). Periodic fires stimulate germination of numerous grasses and flowering plants (Dey et al. 2022) and reduce the density of shade tolerant saplings (Loftis and McGee 1993) which is arguably the most significant impact of fire. Additionally, competition from shade tolerant saplings is the most important factor threatening oak regeneration (Loftis and McGee 1993).

Less desired, shade tolerant species such as red maple (*Acer rubrum* L.), sugar maple (*Acer saccharum* Marsh.), black birch (*Betula lenta* L.), redbud (*Cercis canadensis* L.), hackberry (*Celtis occidentalis* L.), green ash (*Fraxinus pennsylvanica*) and American elm (*Ulmus americana* L.) are aggressive in an understory and are replacing oaks due to the suppression of fire. Shade tolerant species have characteristics that allow them to grow in low light conditions (Dey 2002), therefore challenges arise when attempting to maintain them to low densities for oak regeneration. Decades of fire suppression can lead to a dense canopy composed of fire sensitive, shade tolerant trees. A high density of shade tolerant mesophytic species reduces the flammability of oak-hickory stands by promoting a damp, cool litter layer (Abrams 2016). These shade tolerant species eventually produce the majority of the litter layer which dries slower and burns less vigorous which makes using fire less effective. Previous research indicates leaf litter produced by oak competitors is less flammable than litter produced by fire tolerant species (Babl et al. 2020). Furthermore, a lack of fire leads to an accumulation of litter in forest

floors, resulting in reduced species diversity in the understory plant community (Hiers et al. 2007, Engber et al. 2011). A thick litter layer reduces the amount of sunlight reaching the soil resulting in a cool soil temperature which decreases seed germination. This level of stress restricts the number of species able to germinate. However, reducing the fire frequency is the most important disturbance dynamic for understory species diversity and density which has been thoroughly examined (Brockway and Lewis 1997, Glitzenstein et al. 2003).

Fire is one of many effective techniques that can be used to manage woodlands. Herbicide application and thinning are often combined with fire to produce the most effective results for woodland management and restoration. Mechanical thinning targets specific individuals using chainsaws (Abella et al. 2001, Nielson et al 2003), machinery, or heavy equipment such as harvesters or bulldozers (McCarty 1998, Asbjornsen et al 2007). Thinning intensity (i.e. number of trees, basal area, or volume to be removed in a stand) will vary based on management goals, and current state of the woodland. Reducing canopy cover via thinning often results in an increase in woody regeneration and herbaceous ground cover which can be managed using brush saws, mowing, herbicide, and fire (Choi and Pavlovic 1998). Thinning alone can increase herbaceous cover in woodlands (Perchemlides et al. 2008), and species richness (Ares et al. 2009), which is desirable from a wildlife management standpoint. Foresters and silviculturists recognize that large canopy disturbances must occur to secure oak regeneration on sites of moderate productivity (Schweitzer and Dey 2011). However, caution must be used when prescribing canopy reductions because over thinning could increase understory competition and suppress hardwood regeneration (Dey 2014, Miller et al. 2017).

Mechanical thinning in combination with fire is frequently used to encourage oak regeneration and decrease shade tolerant species and is the preferred technique in oak woodland restoration (Dey et al. 2017). Promising results have been shown when thinning is followed by a fire to encourage oak regeneration, especially in the eastern oak forest (Knapp et al. 2009, Dey et al. 2017, Galgamuwa et al. 2018). Iverson et al. (2008) found that burning and mechanical thinning treatments resulted in the most advanced oak and hickory regeneration (>50cm height) one year post fire. Similar mechanical thinning and prescribed fire techniques have produced comparable results for oak regeneration. Galgamuwa et al. (2018) found the most effective treatment for oak regeneration is a combination of prescribed fire and mechanical thinning, while also reducing competitor species.

The overall objective of our research was to determine the long-term effects (10 years) of two prescribed fires and two mechanical thinning treatments on species composition and stand structure in an oak hickory woodland in Northeast Kansas. We hypothesized that: 1) prescribed fire and prescribed fire coupled with thinning would produce the greatest increase in oak seedlings, 2) thinning treatments would have the overall largest number of seedlings per acre, 3) prescribed fire and prescribed fire coupled with thinning would have the least competition from primary competitor species.

Methods

Study Site and Experimental Design

The study was conducted at the Howe Natural Resources Education Center, owned by Kansas State University Department of Horticulture and Natural Resources (96°40'41.316"W, 39°19'37.938"N). The 145-acres property is composed of chinkapin oak (*Quercus muehlenbergii* Engelm.), bur oak (*Quercus macrocarpa* Michx.) black walnut (*Juglans nigra* L.), bitternut

hickory (*Carya cordiformis* (Wangenh.) K. Koch), Eastern redcedar (*Juniperus virginiana* L., hereafter 'ERC') hackberry, American elm, and redbud, and one native grass hay meadow. The upper slope and hilltop areas of the site are dominated by ERC. Therefore, only the lower slopes and lowland areas were used for the study. The site index assessed by Galgamuwa et al. (2018) was estimated at 40 feet (12.19 m) at age 50, which indicates a low-quality site. Site index was estimated by selecting 15 free growing, dominant, or codominant chinkapin oak trees and extracting core samples from different locations across the study area. Site index curves for chestnut oak (*Quercus montana* Willd.) in the central states were used as a surrogate in the assessment (Carmean 1971). The average age of the trees was 72 years with an average height of 49 ft (14.94 m).

A randomized complete block design was used for the study site. We used a two-way factorial design with two levels of burn (burned and unburned) and two levels of thin (thinned and non-thinned). Natural drainages were used as boundaries, when possible, for convenience of creating fire breaks. Slopes were recorded as 20% to 40% (USDA NRCS 2017) and elevations range between 335ft (102 m) to 402ft (123 m). The project design by Galgamuwa et al. (2018) included dividing the study area into three large blocks based on topography. The blocks were further divided into split plots, with thinning randomly assigned to them. Each block contained four compartments; each compartment randomly had one treatment assigned. Treatments were burn only (B), thin only (T), burn & thin (BT), control (C). Each treatment had 3 replicates, totaling 12 compartments, each compartment ranged in size from 6 to 10 acres (2.43-4.05 ha). Once the 12 compartments were delineated, 91 t-posts were set throughout the study area to mark plot centers at a frequency of 1 plot/acre (0.4 ha) (Figure 1.1).

Data Collection

Data collection occurred on all 91 plot centers. Two microplots were established 18.5 ft. 90° (east) and 270° (west) from the plot center as a fixed area for all data collection. Saplings (1 in. [2.45 cm] to 4.9 in. [12.45 cm] dbh) were recorded and identified inside a 1/100-acre area [11.8 ft. (3.6 m) radius]. Seedlings (>1.0 in. [2.54 cm] dbh, >12 in. [30.48 cm] tall) were identified and recorded within a 1/300-acre area (6.8 ft. [2.1 m] radius), and mature tree data was collected on a 1/10-acre fixed radius area (37.2 ft. [11.34 m] radius) (Figure 1.2). The Forest inventory and Analysis protocol (USDA FS 2016) criteria was followed where hardwoods must be at least 12 in. (30.48 cm) tall to be counted as a seedling and coniferous seedling must be at least 6 in. (15.24 cm) in height. These plot centers have been consistently used to sample the stand inventory since 2014 for two research projects (Galgamuwa et al. 2018, Simões 2019).

Data collection for litter and fuel load (FL) were collected at 38 of the 91 plot centers in the burn only and burn and thin areas in 2023. Data collection for FL followed the FIREMON sampling protocol (DWD and duff/litter profile) and were processed using the FFI-Lite (FEAT FIREMON Integrated) version 1.05.03.09, management tool software (Lutes et al. 2006). This software summarizes a report in tons per acre of duff, litter, and total fuel load for each compartment. The planar intercept method was used to measure DWD. We established four transects from the plot center at 90°, 330°, 270°, and 210°. We divided the DWD into four classes based on the time each class takes to adjust to moisture conditions. The classes were 1-hour (0.0 to 0.25 in. [0.64 cm]), 10-hour (0.25 in. [0.64 cm] to 1.0 in. [2.54 cm]), 100-hour (1.0 in. [2.54 cm] to 3.0 in. [7.62 cm]) and 1000-hour (greater than 3.0 in. [7.62 cm]) fuels.

We collected the 1- and 10-hour fuels that crossed the sampling place from 15 to 21ft. (4.57m- 6.4m) from the plot center. The 100-hr were counted from 15 to 30 ft. (4.57m- 9.14m), and 1000-hour fuels 15 to 75 ft. (4.57m- 22.86m) from the plot center. At 45 ft. (13.72m) and 75 ft. (22.86m) from the plot centers, duff and litter was recorded on the sampling plane (Figure 1.3). Duff was classified as lower, heavily decomposed plant material, and litter was classified recently fallen plant material (<2 years old). FL means from 2023 were converted to tons per acre using the FFI-Lite software and analyzed and compared to means from 2014.

Treatments

The inventory conducted in 2014 showed that a single compartment had a stocking higher than 100% (overstocked) and the remaining 11 compartments were fully stocked with a stocking between 60% and 100% (Galgamuwa et al. 2018). The average basal area and density was 100 ft²/acre (22.96 m²/ha) and 162 trees per acre (TPA), respectively (Galgamuwa et al. 2018). The first thinning was conducted in January 2015 to reduce the stocking to the recommended stocking level for woodland restoration of 55% to 70% (Hanberry et al. 2017) by removing 25 TPA (62 TPha) of ERC, American elm, and hackberry. The target for overstory thinning was set to reduce the stocking to <60% (B-line in the Gingrich stocking diagram) (Gingrich 1967; Figure 1.4) to maintain fully stocked for both thinning prescriptions. Saplings were removed at a rate of 50 per acre (124 stems per ha) of American elm, eastern redbud, ERC, and hackberry (Galgamuwa et al. 2019).

Trees were classified with a diameter breast height (dbh) $\geq$ 5in (12.7cm), and stems from 1 in (2.45cm) to 4.9 in (12.45cm) were labeled as saplings. A second thinning was conducted in February 2018 and procedures were similar to the first thinning, except the prescription varied

per compartment according to the compartment stocking. Some low vigor oaks were girdled to meet the stocking reduction goals. In both thinning operations, trees were single girdled, and saplings were felled and 25% Garlon-4 mixed with diesel fuel was applied to the cut surface to prevent resprouting.

Prescribed burns were conducted by the Kansas Forest Service and Kansas State University staff. The first burn occurred in April 2015, a dormant season fire with air temperature of 75°F, 33% relative humidity, and a 20ft wind speed of 4-6 mph Galgamuwa et al. (2019). The fire behavior was mild with flame length 6- to 12- in (15.2- 30.5cm) and spread 5- to 10-ft/min (1.52- 6.1 m/min). The second burn occurred in May 2018, which was later than originally planned because the fuel was too wet. Air temperature was 75°F with relative humidity of 50%, and a wind speed of 7 mph (Simões et al. 2019), and the woody species were starting to leaf out. Research has been conducted on seasonal effects of burning oak timber stands and found basal areas of overstory and understory were unaffected by season of burn, and mesophytic species seedlings increased after a growing season burn. They also concluded a growing season burn had no effect on red or white oak, and red maple (Keyser 2019)

Data Processing and Statistical Analysis

We used statistical models to determine factors affecting seedling, sapling, and mature tree composition and structure. Factors consisted of 1) time since burn (TSB), and 2) treatment. Time since burn and year were confounded because burn year was the same for all areas treated with prescribed fire. Response variables consisted of 1) saplings per acre (SapPA) 2) seedlings per acre (SeedPA), 3) trees per acre (TPA), 4) basal area (BA), and 5) fuel load recovery (FL). Saplings, seedlings, and mature tree count datasets for the east and west microplot were averaged

from 2020 to 2022 and their means were converted to SeedPA, SapPA, and TPA and by species. TPA and dbh data was used to calculate BA by species. Species were grouped into categories for the final analysis: oaks (chinkapin oak [*Quercus muehlenbergii*], bur oak [*Quercus macrocarpa*], black oak [*Quercus velutina*]), walnut and hickory (black walnut [*Juglans nigra*], bitternut hickory [*Carya cordiformis*]), primary competitors (American elm, Eastern redcedar, hackberry), redbud, and others (green ash [*Fraxinus pennsylvanica*], honeylocust [*Gleditsia triacanthos*], Kentucky coffeetree [*Gymnocladus dioica*], Osage-orange [*Maclura pomifera*], red mulberry [*Morus rubra*]).

Data analysis was conducted in R (R version 4.2.2; R Core Team 2022). Functions in the base packages were used to test for changes in response variables over three growing seasons using ANOVA and MANOVA. We tested for significance in treatment, TSB, SeedPA, and SapPA. We tested for differences in group means between SeedPA and SapPA using Tukey tests. Means were considered significantly different at a $p < 0.05$. We also assessed differences in TPA, BA, and FL to a previous study from the site (Galgamuwa et al. 2018) using pairwise comparisons of means

Results

Seedlings

Our MANOVA was significant indicating that species composition was affected by treatment (Wilks lambda = 0.6, $df=3$, $F= 4.77$, $p < 0.001$). The one-way ANOVA for treatment was significant for primary competitor ($p < 0.05$, $df=3$, $F=8.36$) and redbud seedlings ($p < 0.01$, $df=3$, $F=4.19$). The one-way ANOVA for Time Since Burn was significant only for oak seedlings ($p=0.03$, $df=1$, $F=4.57$). Walnut and hickory, and the primary competitor group were marginally significant for the one-way Time Since Burn interaction ($p=0.06$, $df=1$, $F=3.47$,

$p=0.06$, $df=1$, $F=3.42$, respectfully). The two-way interaction between treatment and Time Since Burn was not significant for any species groups. The Tukey's test for the primary competitor's species group was significant for Thin Only and Burn Only, Burn and Thin and Burn Only, and Control and Burn and Thin ($p<0.05$, $p<0.01$, $p<0.05$, respectively). Redbuds also were significant for the Tukey's test with significance in Thin Only and Burn Only, and Thin Only and Burn and Thin ($p<0.05$, $p<0.05$). The remaining species groups were not significant for the Tukey's test.

During our last season of data collection, oaks were least abundant in Burn and Thin areas (336 seedlings per acre; Figure 1.5) and had a 13 seedling per acre decrease from 2014 to 2023 in these areas (Figure 1.6). They increased by 103 seedling per acre in Control areas, increased by 295 seedling per acre in Burn Only areas, and 274 seedling per acre increase in Thin Only areas. Redbud seedlings per acre increased significantly in all treatments since 2014, with the two greatest increases in the Control (3,913 seedling per acre increase) and Thinned (5,418 seedlings per acre increase) areas. Primary competitor seedlings were also significantly different within treatments, with the highest densities from our last season of data collection in Burn and Thin areas (2,450 seedlings per acre) and Thin Only areas (1,807 seedlings per acre). The Thin Only areas had the greatest increase in total seedling per acre from 2014 (7,414 seedling per acre increase) largely made up of redbuds, followed by Control areas (5,154 seedling per acre increase), and Burn and Thin areas (3,408 seedling per acre increase) and Burn Only areas (2,519 seedling per acre increase).

Saplings

Our MANOVA results were significant for treatment (Wilks lambda = 0.6, $p < 0.001$, $df=3$, $F=4.78$). The one-way ANOVA for treatment was significant for all species groups except those categorized as 'other'. Oaks ($p < 0.01$, $df=3$, $F=5.59$), walnut and hickory ($p < 0.01$, $df=3$, $F=4.88$) primary competitor ($p < 0.01$, $df=3$, $F=11.4$), redbud ($p < 0.01$, $df=3$, $F=7.19$), and other ($p=0.17$, $df=3$, $F=1.71$). Oaks were most abundant in the Thin Only areas (48 saplings per acre) compared to Burn and Thin (8 saplings per acre), Burn (22 saplings per acre), and Control (28 saplings per acre)(Figure 1.7). Since 2014, Thin Only had the greatest reduction in oak saplings per acre (30 saplings per acre reductions) compared to the Control (13 sapling per acre increase) and Burn Only and Burn and Thin both had an increase of two saplings per acre (Figure 1.8).

The two-way interaction between Time Since Burn and treatment was not significant for any sapling groups. The Tukey's test for Time Since Burn was not significant for any species groups. The Tukey's test for treatment was significant for oak saplings with combinations Thin Only and Burn and Thin, and Thin Only and Burn Only ($p < 0.001$, $p < 0.05$, respectfully), walnut and hickory were significant for Control and Burn Only, and Control and Burn and Thin ($p < 0.05$, $p < 0.05$, respectively). Primary competitor saplings were significant for treatment combinations Control and Burn Only, Control and Burn and Thin, Thin Only and Burn and Thin, and Thin Only and Control ($p < 0.001$, $p < 0.001$, $p < 0.05$, $p < 0.05$, respectively), redbud saplings were significant for treatment combinations Thin Only and Burn Only, Thin Only and Burn and Thin, and Thin Only and Control ($p < 0.001$, $p < 0.001$, $p < 0.05$, respectfully) and species categorized as 'other' were not significant for any treatment combinations

Mature Trees Per Acre

Thin only and burn and thin showed similar results for decreasing overall trees per acre, averaging 74 trees per acre reduction from 2014 to 2023. Burn and Thin was the most effective treatment at reducing Eastern redcedar resulting in a complete eradication in 2023. Eastern redcedar decreased by 18 trees per acre in the Thin Only areas compared to a 5 trees per acre increase in the Burn Only areas and 6 trees per acre increase in the Control areas. Since 2014, oaks decreased in the Control areas by 4 trees per acre, decreased in the Thin areas by 16 trees per acre, decreased by 35 trees per acre in the Burn and Thin areas, and increased by 1 tree per acre in the Burn Only areas. Oaks were the most abundant species in all treatments but had the highest densities in the Burn Only areas and Thin Only areas (Figure 1.9). Walnut and hickory had the highest abundance in Control areas (35 trees per acre) followed by Burn Only (20 trees per acre) with the lowest trees per acre in Burn and Thin areas (9 trees per acre).

Primary competitors had the highest abundance in the Burn Only areas (36 trees per acre) mainly composed of Eastern redcedar and hackberry and had the lowest abundance in the Burn and Thin areas (4 trees per acre). Species classified as ‘others’ were most abundant in Burn Only areas (10 trees per acre), followed by Control areas (5 trees per acre) and absent in the Thin Only areas. Burn and Thin areas had the lowest overall trees per acre in 2023 (65 trees per acre) compared to 141 trees per acre in 2014

Mature Tree Basal Area

Eastern redcedar had the greatest increase in the Control areas at a 14 ft²/ac increase. The oaks group increased in basal area in all treatments except the Burn and Thin area. Oaks had the greatest increase in the Burn Only increased by 33 ft²/ac, compared to a 24 ft²/ac increase in the Control areas, 25 ft²/ac increase in the Thin Only areas, and 16 ft²/ac decrease in the Burn and Thin areas (Figure 1.10), but this did not occur at a significant level ($P>0.05$).

Fuel Load Recovery

Our data was collected 5 growing seasons after the last burn. Duff, litter, and total fuel load was first assessed pre-burn 2015 and was recorded immediately after both burns. The one-way ANOVA for our 2023 means within treatment were significant for duff ($p<0.01$, $df= 3$, $F= 8.4$), litter ($p<0.01$, $df= 3$, $F= 28.5$), and total fuel load ($p<0.01$, $df= 3$, $F= 22.9$). In 2015, pre-burn duff layer was recorded at 9 tons per acre and had a 4.5 tons per acre reduction after the first burn, and 4.2 tons per acre reduction after the second burn. Duff layer recovered by 3.4 tons per acre after the first burn and 6.2 tons per acre since the second burn (Figure 1.11). The first burn reduced the litter layer by 5.3 tons per acre, and the second burn removed 8.7 tons of litter per acre. After the first burn, 7.6 tons of litter per acre accumulated following three growing seasons, and 8.8 tons per acre accumulated since the second burn after five growing seasons. (Figure 1.12). Total fuel load decreased by 14 tons per acre after the first burn and decreased by 10 tons per acre after the second burn. Total fuel load recovered by 8 tons per acre after the first burn and 21 tons per acre since the second burn (Figure 1.13)

Discussion

Our 10-year project resulted in considerable findings for promoting oak regeneration on our low index site. With our results we have a better understanding of how oaks and mesophytic species respond to multiple prescribed fires and thinning within the seedling, sapling, and mature tree stages in hardwood systems. We had three main takeaways from our study. 1) There was not a significant difference within oak seedling means per acre within any treatment. Our findings were similar to Simeões et al (2019) where treatment did not affect oak seedling means after two fires and two thinnings. 2) The burn and thin areas had the largest amount of primary competitor species for oaks in 2023. The large number of competitor species may be outcompeting oak species in these areas. 3) Oak sapling and trees were not affected by treatment. Sapling canopy openings are essential for enhancing oak regeneration (Arthur et al. 2012, Dey et al. 2017), but the increased sunlight can negatively affect species composition if not followed by fire. Shade tolerant competitor species such as Eastern redcedar, redbud, American elm, red maple, and green ash often increase after the canopy is opened (DeSantis et al. 2010, Meneguzzo and Linkes 2015, Abrams 2003). The burned and thinned areas had a hotter fire because of the thinned Eastern redcedars which may have top killed some of the oak seedlings in those areas. In our study, redbud seedlings, a major competitor in a large portion of the eastern oak forest (Dey 2014, Iverson et al. 2017), increased significantly in thin only treatments, confirming previous findings from our long-term project (Galgamuwa et al. 2018, Simões et al. 2019). Redbud saplings were least abundant in the burned and thinned areas, and, while targeted in both thinning treatments, remained most abundant in thin only areas.

Oaks have intermediate tolerance of shade, and canopy disturbances have previously promoted oak regeneration (Iverson et al. 2008). Our hypothesis that burning and thinning would

have the greatest increase in oak seedlings was not clearly supported. Our findings align with Alexander et al. (2008) where repeated burning negatively impacted survival and growth of oak groups compared to unburned areas. A potential cause for the decrease in oak seedlings in the burn and thin areas could be due to the reduction in mature oak trees in these areas. Mature oak trees per acre decreased by 35 trees per acre in these areas since 2014 which could be a combination of over thinning and fire mortality. The thinning prescriptions aimed to retain 55-70% stocking rate and could have reduced the number of mature oak trees per acre and resulted in a negative effect for oak seedling recruitment. Similarly, succession is increased after thinning by providing growing space to preexisting understory species, this is true for both woody and non woody species (Abrams and 1992, Holzmüller et al. 2014), potentially increasing competition and reducing oak germination. Thinning however, had the second greatest increase in oak seedling means per acre from 2014 to 2023 but this was not at a significant level, these areas also had the largest number of total seedlings per acre which supported our second hypothesis. Since 2014, oak seedling means increased the most in the burn only areas by 295 seedlings per acre compared to 151 seedling per acre increase in the control. Burn only treatment also had the lowest number of primary competitor seedlings, therefore burning alone increased oak seedling means and reduced the primary competitor species since 2014.

We hypothesized burn only and burn and thin treatments would result in the lowest number of primary competitor species due to their intolerance to fire and inability to resprout after being top killed and physiological characteristics such as exposed dormant buds, thin bark, and lower investment in below ground growth making them more susceptible to fire (Fill et al. 2022). This was supported for burn only areas but was not supported by burn and thin areas. Previous observations have shown when thinning is not followed by fire, fast growing

competitor species will accelerate (Albrech and McCarthy 2006). Thinning has an advantage over fire in selecting competitive, undesired adult tree species while controlling basal area and density (Arthur et al. 2012, Dey et al. 2017) which was supported in our study. By targeting competitor trees and saplings in the thinning treatment, we were able to reduce competitor trees per acre and saplings per acre, although the seed bank may have contained seeds from these species, thus germinating immediately after the thinning occurred. Increasing fire frequency is often used to counter this flush in undesired seedlings after thinning and has shown promising results to reduce seedlings per acre in an oak woodland (Peterson and Reich 2001). A shorter fire return interval may be needed to reduce the number of competitive seedlings, thereby allowing oaks to germinate. It is important to note the second fire occurred during the early growing season which may have caused oak seedling mortality.

In addition to oaks, walnut and hickory species provide valuable timber and are major components in hardwood systems (Burns and Honkala 1990, Fralish 2004) and share similar management practices as oaks. Seedlings and saplings for walnut and hickory, and the category ‘other’ were not affected by treatment, likely because of the low abundance of these species present on the property. Since 2018 burn only treatments had the greatest increase in basal area for oak, walnut and hickory. The increase in basal area for these species demonstrates that burning alone can allow desired species to increase in basal area which is of value for timber producers.

Fuel load reduction after fire can be beneficial for oak regeneration. There was successful total fuel load consumption after the two burns (Galgamuwa et al. 2018, Simões 2019). Total fuel load increased by 10 tons per acre between the second burn and 2023, this was a larger increase than between the first and second burn, indicating that fuel load increases as time since

fire increases. Fire can negatively impact oak regeneration if the duff layer is too thin by heating up the acorns to a temperature where they become susceptible to desiccation (Lutes et al. 2006). Both fires produced similar results for decreasing total fuel load. Since there wasn't thinning following the second burn, there was not a significant increase in total fuel load as Galgamuwa et al. (2018) and Simões (2019) observed. The 2023 litter load was similar to the 2018 pre burn litter load. This explains why there is not a significant difference between litter accumulation withing 3- and 5-years post burn.

The results of our field research demonstrate prescribed fire can be used to promote oak regeneration in Kansas. Our field study combined findings from previous studies that show prescribed fire can increase oak seedling means while reducing competitor species. We propose repeated prescribed fires with a shorter fire return interval should occur before we see a significant change in oak seedling abundance. We demonstrated thinning needs to be followed by fire to reduce a large flush in fast growing species (i.e., redbud, American elm, hackberry, Eastern redcedar). After the first burn on this study Galgamuwa et al. (2019) proposed the increase in redbud seedlings could remain a challenge for oak regeneration, this remained true through our study and needs to be further addressed. Fire frequency should be strongly considered when implementing ecological restoration goals in hardwood systems. In the future, fire frequency studies are needed to ensure effective mortality on competitor species, while maintaining an adequate number of oak seedlings

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Table 1.1. Mean seedlings per acre from 2020 to 2022 at the Howe Natural Resources Education Center, Manhattan, Kansas.

	Burn & Thin	Control	Thin	Burn	P-value
-----Seedlings per acre means from 2020-2022-----					
Oaks	336	692	670	644	0.09
Walnut & Hickory	465	424	482	329	0.42
Primary Competitor	2450	1611	1807	1072	<0.01
Redbud	2066	4659	5995	2107	<0.01
Other	70	26	68	33	0.2

Table 1.2. Mean saplings per acre from 2020 to 2022 at the Howe Natural Resources Education Center, Manhattan, Kansas.

	Burn & Thin	Control	Thin	Burn	P-value
-----Sapling per acre means from 2020-2022-----					
Oaks	8	25	49	22	<0.01
Walnut & Hickory	14	38	26	12	0.02
Primary Competitors	7	184	97	65	<0.01
Redbud	5	37	89	11	<0.01
Other	3	3	3	10	0.16

Table 1.3. Trees per acre and basal area means from 2014 to 2023 at the Howe Natural Resources Education Center, Manhattan, Kansas.

Response	Control		Thin		Burn		Burn & Thin	
Variable	2014	2023	2014	2023	2014	2023	2014	2023
-----Trees per acre-----								
Total	146	140	179	106	182	151	141	66
Oaks	70	66	97	81	83	84	87	52
ERC	17	23	22	4	14	19	6	0
-----Tree basal are (ft ² /ac)-----								
Total	9	142	93	10	102	157	115	87
Oaks	55	79	56	81	61	94	87	72
ERC	5	19	11	5	8	17	3	0

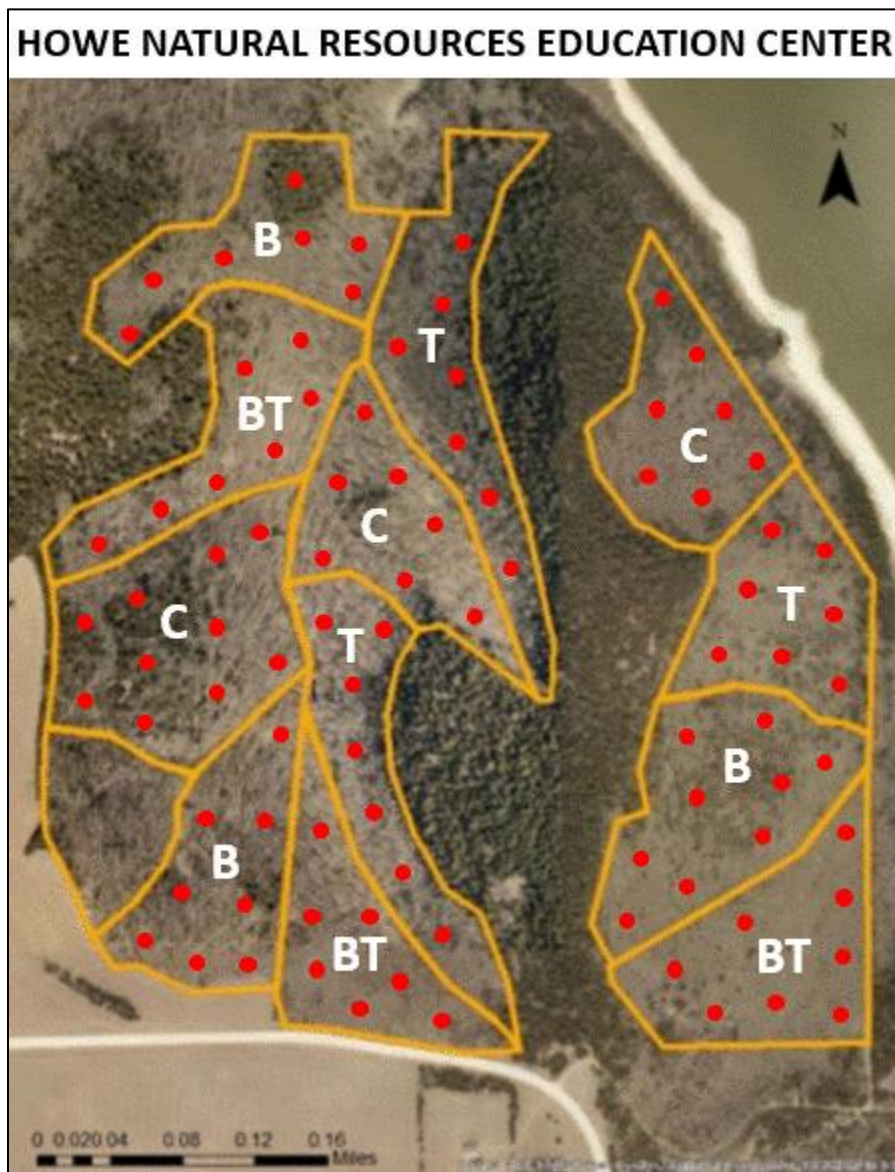


Figure 1.1. Experimental layout with four treatments, and three replicates of each treatment; “Control” (C) “Thin Only” (T), “Burn Only” (B), and “Burn and Thin Combined” (BT). In total, 91 permanent data collection points were established throughout the study area. Burns and thinnings occurred in 2015 and 2018.

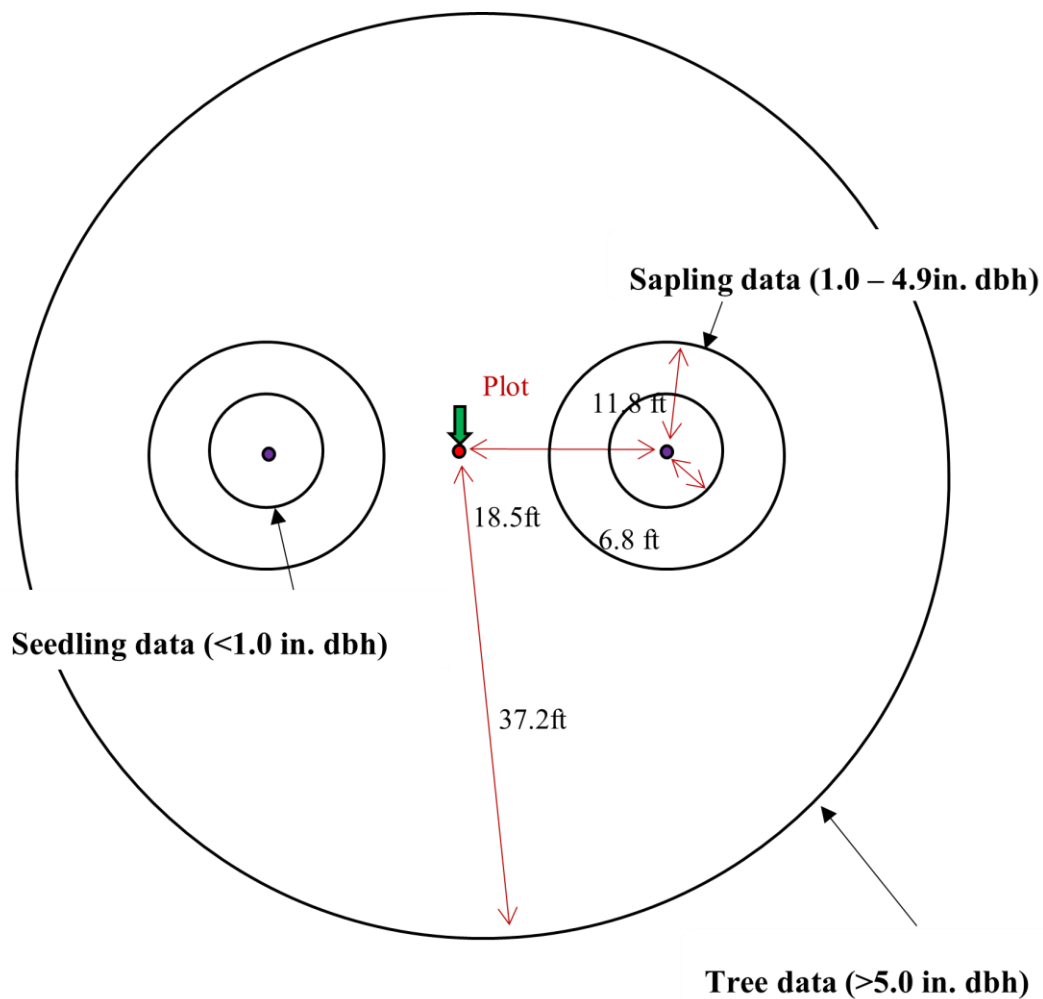


Figure 1.2. Permanent data collection point (plot centers) structure for seedlings, saplings and mature trees.

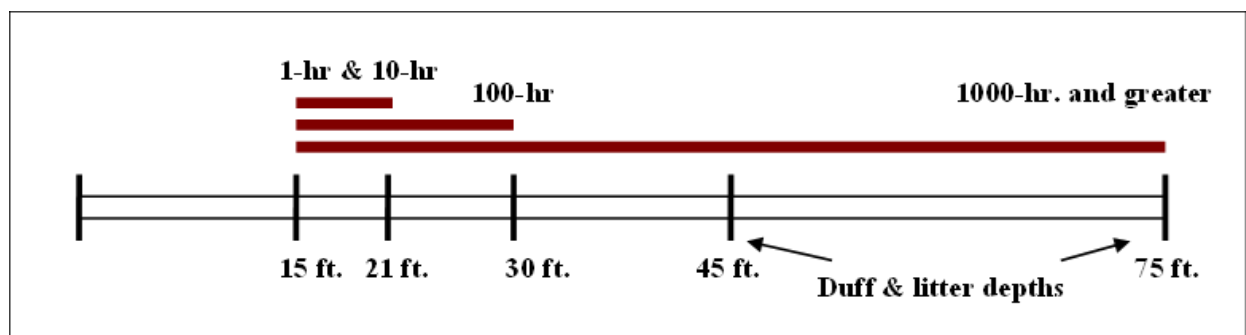


Figure 1.3. FIREMON sampling plane layout (1 transect) for the fuel load estimation (Lutes et al. 2006).

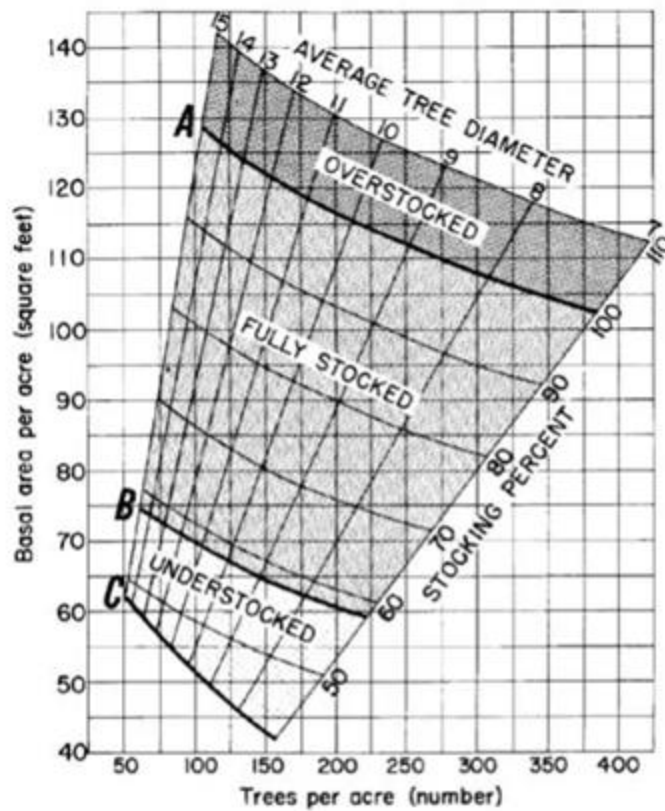


Figure 1.4. Stocking chart for measuring and evaluating stand density in upland hardwood forest in Central United States using basal area per acre, average trees per acre, and average tree diameter. The area between the A and B curve indicates the range of stocking where trees can fully utilize the growing space. The diameter of trees range between 7-15in. Curve C shows the lower limit of stocking necessary to reach the B level in 10 years on average sites (Gingrich, S.F. 1967).

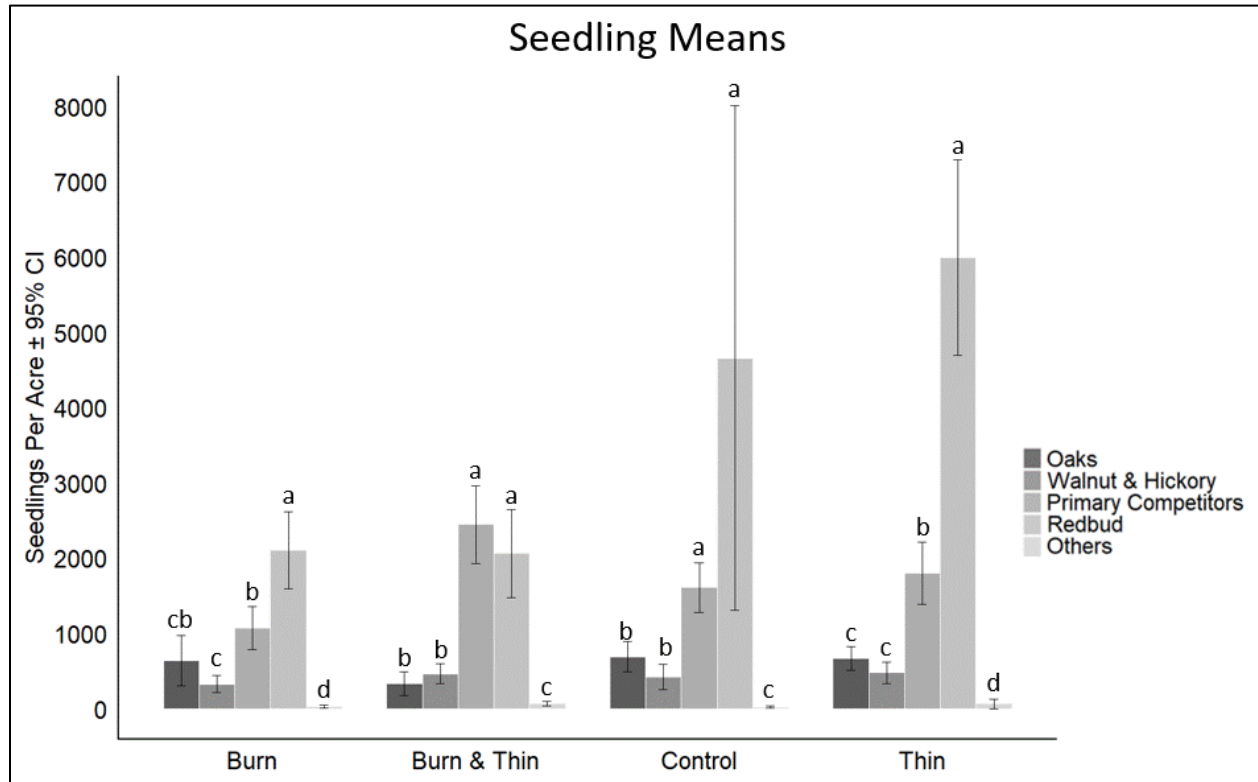


Figure 1.5. Group means comparison of seedlings per acre of years averaged from 2020-2023 at the Howe Natural Resources Education Center, Manhattan, Kansas. Treatments are burn only, burn and thin, control, and thin only, treatments occurred in 2015 and 2018. Species groups are oaks (chinkapin oak, bur oak, black oak), walnut & hickory, primary competitors (Eastern redcedar, hackberry, American elm), redbud, and others (Kentucky coffeetree, red mulberry, honey locust, green ash). Bars sharing letters above confidence intervals indicate significance.

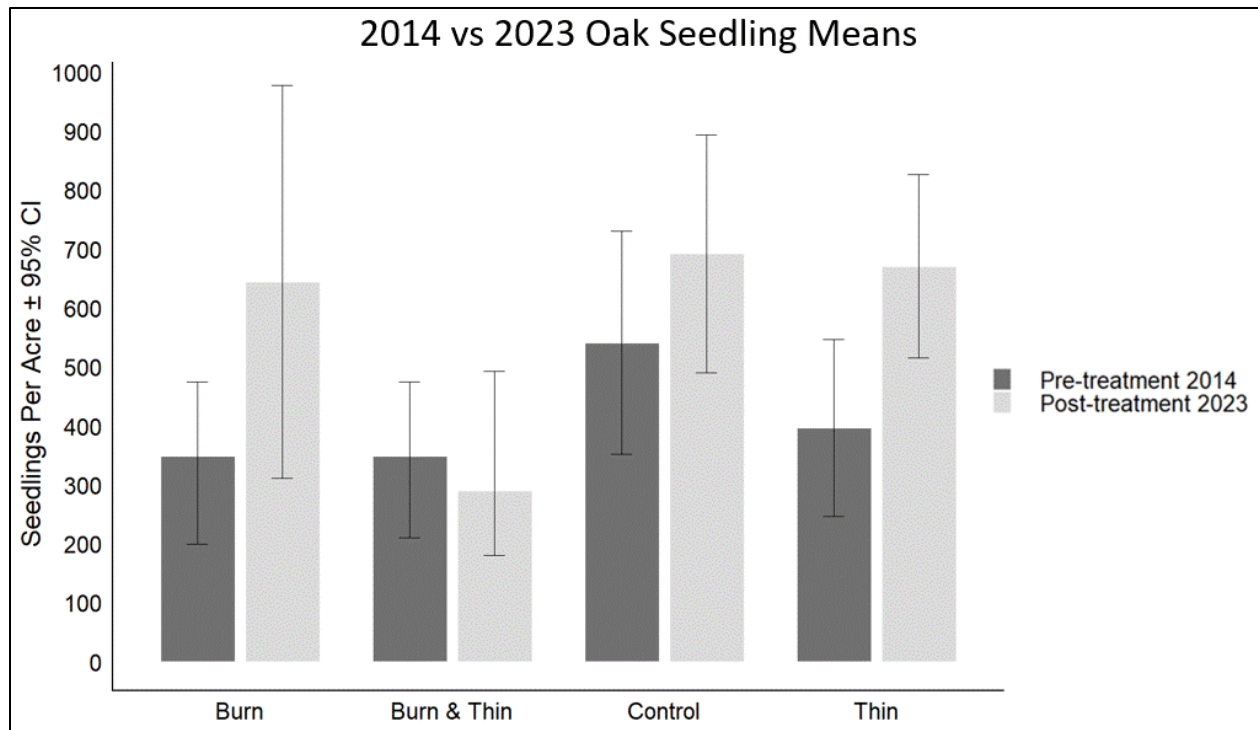


Figure 1.6. Group means comparison of oak seedlings per acre from pre-treatment 2014 and post-treatment 2023 at the Howe Natural Resources Education Center, Manhattan, Kansas. Oaks consist of chinkipin oak, black oak, and bur oak. Treatments are burn only, burn and thin, control, and thin only, treatments occurred in 2015 and 2018. Bars sharing letters above confidence intervals indicate significance.

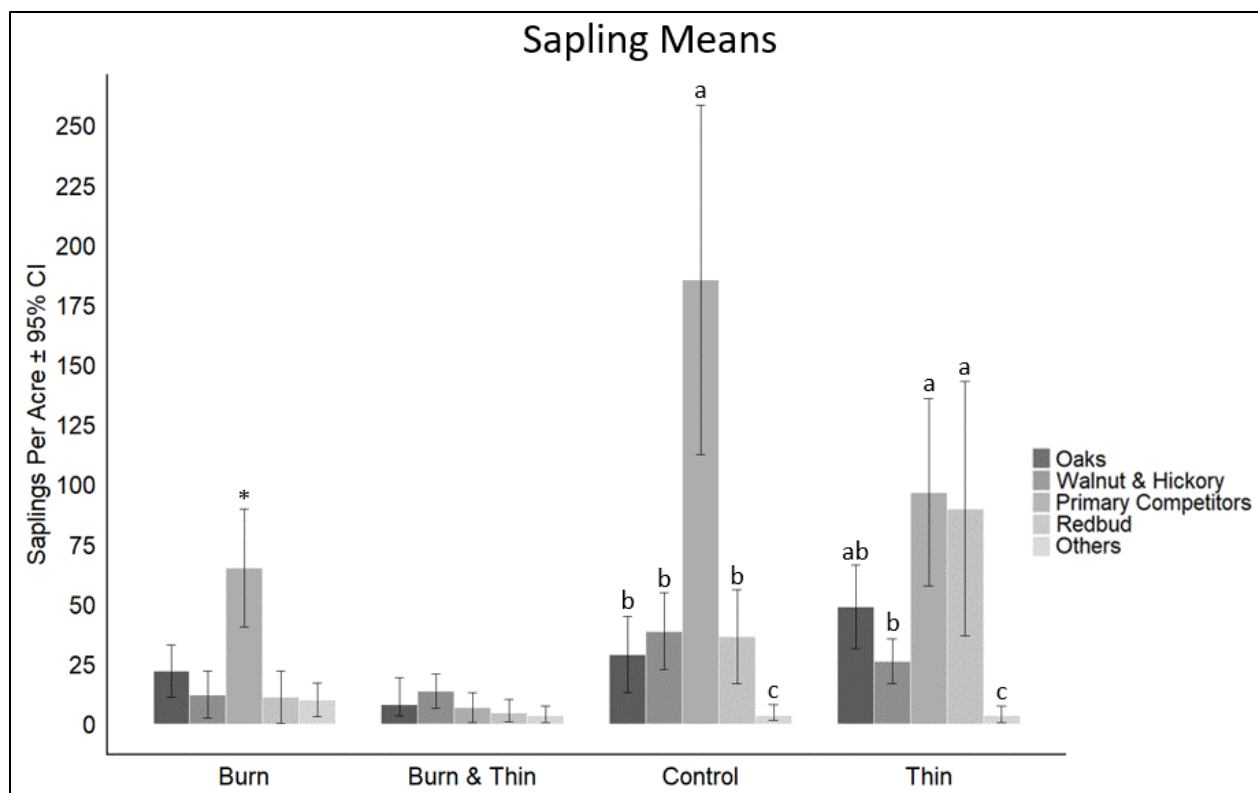


Figure 1.7. Group means comparison of saplings per acre of years averaged from 2020-2023 at the Howe Natural Resources Education Center, Manhattan, Kansas. Treatments are burn only, burn and thin, control, and thin only, treatments occurred in 2015 and 2018. Species groups are oaks (chinkapin oak, bur oak, black oak), walnut & hickory, primary competitors (Eastern redcedar, hackberry, American elm), redbud, and others (Kentucky coffeetree, red mulberry, honey locust, green ash). Bars sharing letters above confidence intervals indicate significance.

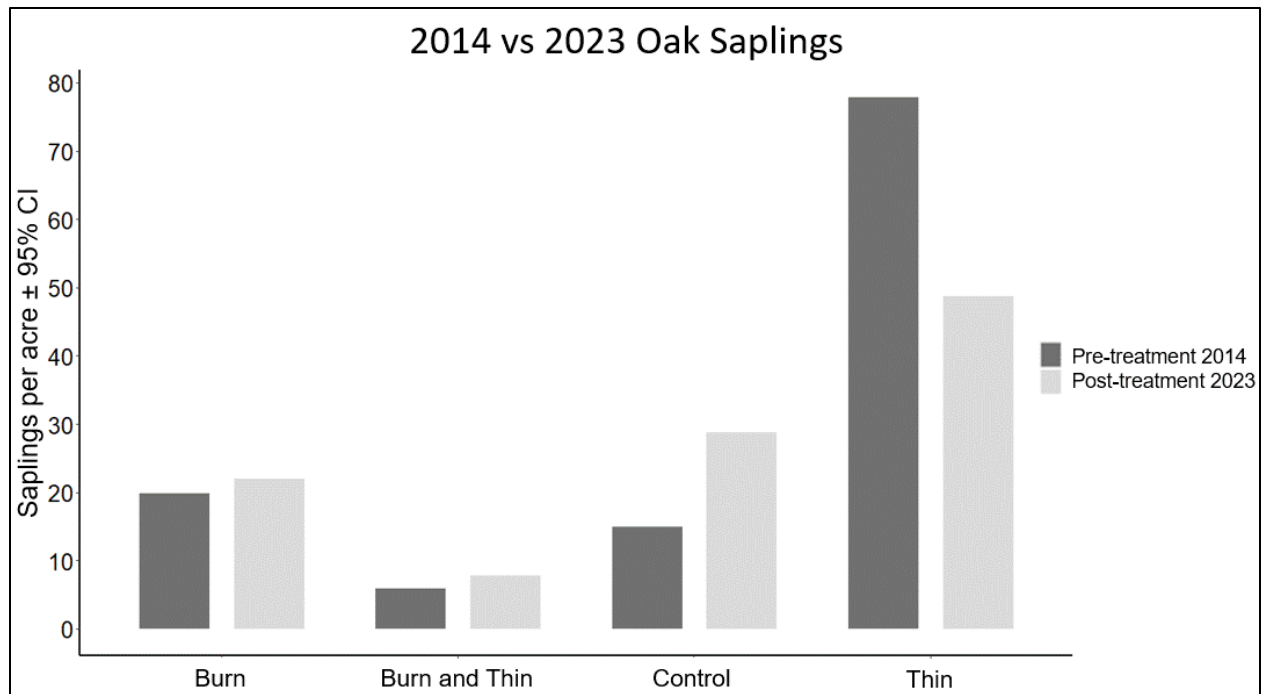


Figure 1.8. Group means comparison of oak saplings per acre from pre-treatment 2014 and post-treatment 2023 at the Howe Natural Resources Education Center, Manhattan, Kansas. Treatments are burn only, burn and thin, control, and thin only, treatments occurred in 2015 and 2018.

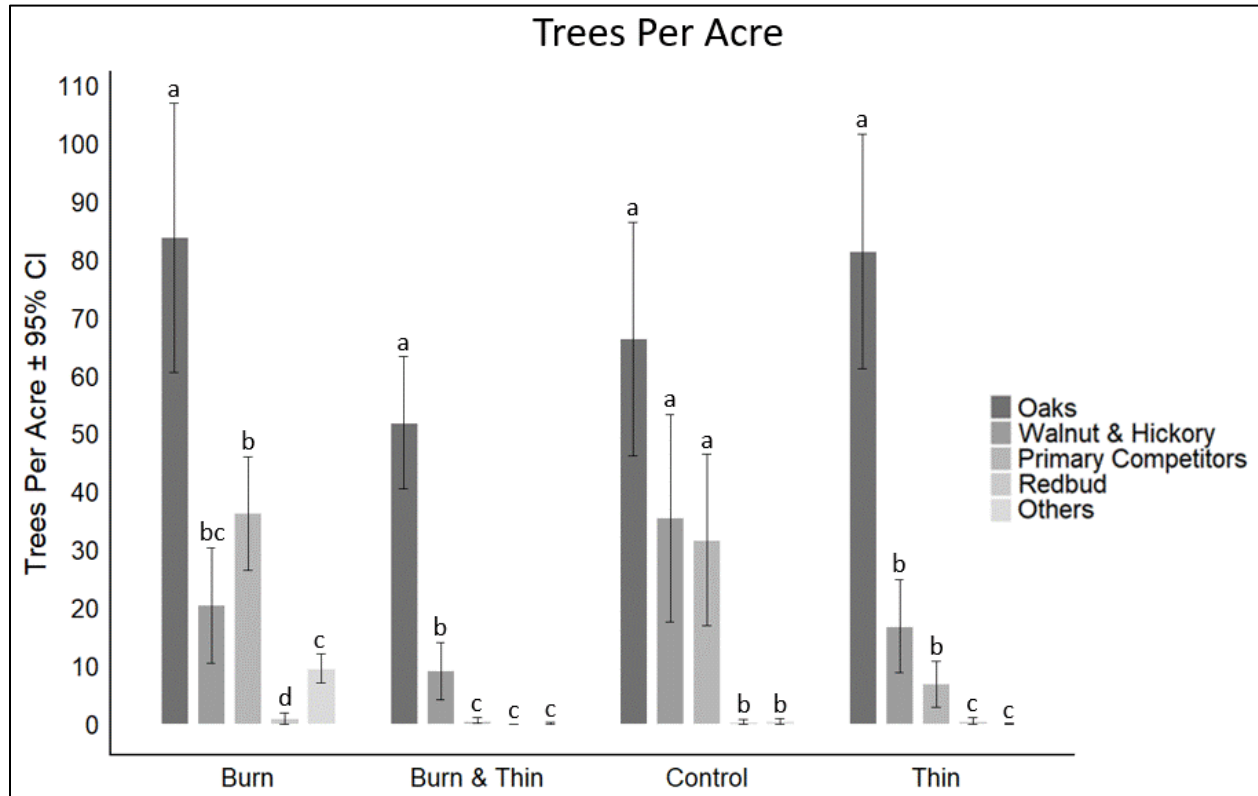


Figure 1.9. Group means comparison of trees per acre of years averaged from 2020-2023 at the Howe Natural Resources Education Center, Manhattan, Kansas. Treatments are burn only, burn and thin, control, and thin only, treatments occurred in 2015 and 2018. Species groups are oaks (chinkapin oak, bur oak, black oak), walnut & hickory, primary competitors (Eastern redcedar, hackberry, American elm), redbud, and others (Kentucky coffeetree, red mulberry, honey locust, green ash). Bars sharing letters above confidence intervals indicate significance.

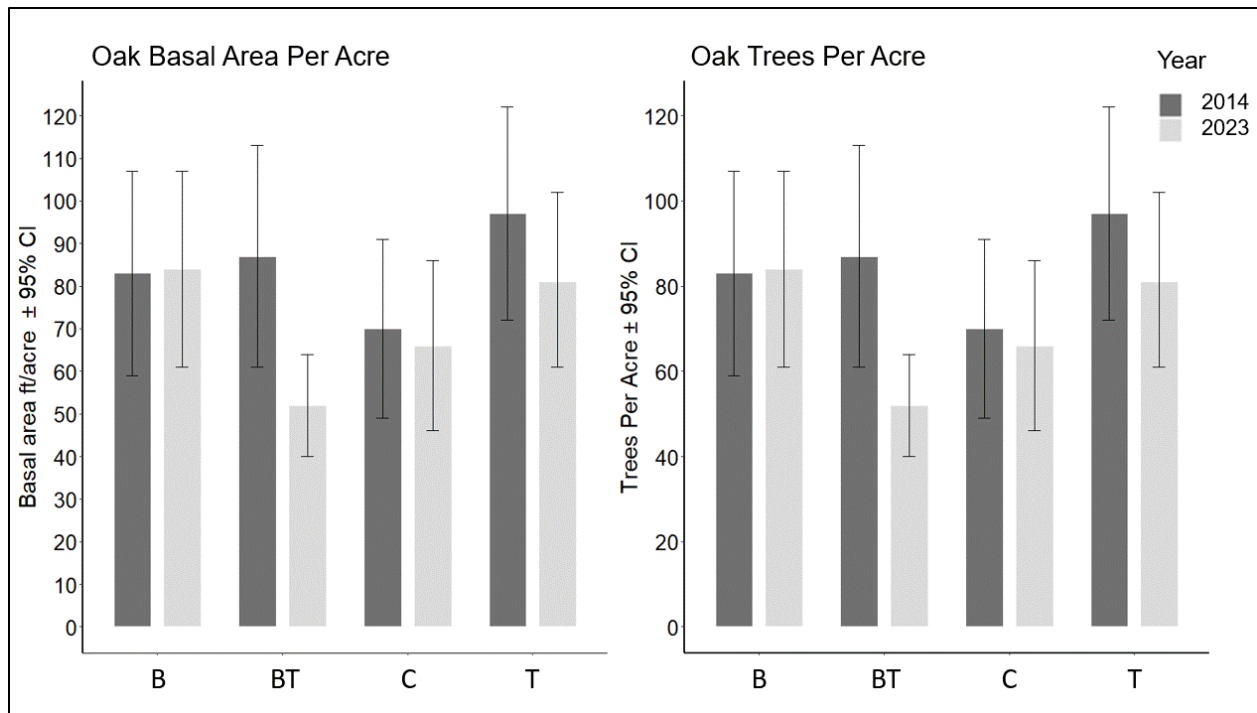


Figure 1.10. Grouped bar chart showing basal area (left) and trees per acre (right) for oaks (chinkapin oak, bur oak, black oak) from pre-treatment (2014) to post-treatment (2023) after two burns and two thinnings at Howe Natural Resources Education Center, Manhattan, Kansas. Treatments occurred in 2015 and 2018, (B) Burn Only, (BT) Burn and Thin, (C) Control, (T) Thin Only.

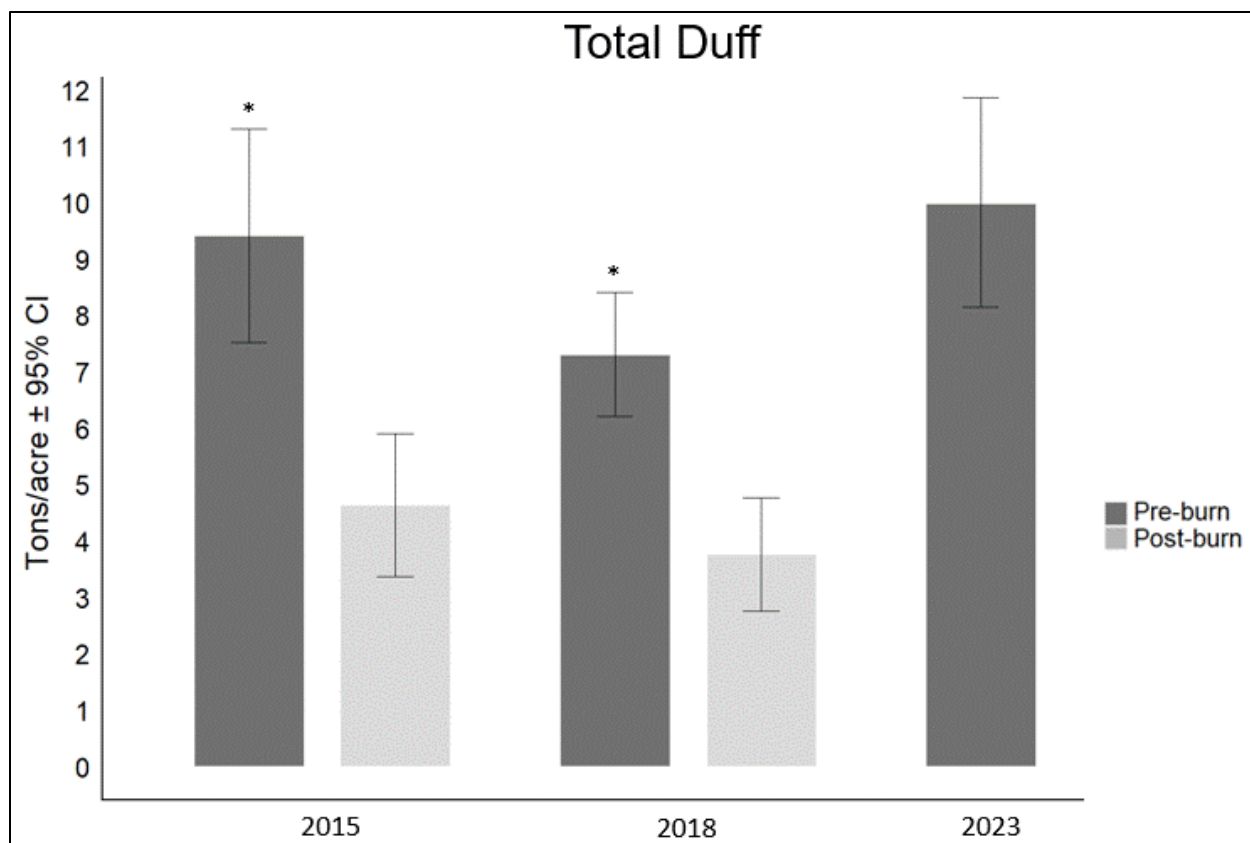


Figure 1.11. Bar graph comparing total duff consumption and recovery from two prescribed burns at Howe Natural Resources Education Center, Manhattan, Kansas. Prescribed burns occurred in 2015 and 2018, there was not a burn from 2018 to 2023. Values are combined means from burn only and burn and thin areas. Asterisks above error bars indicate significance within year.

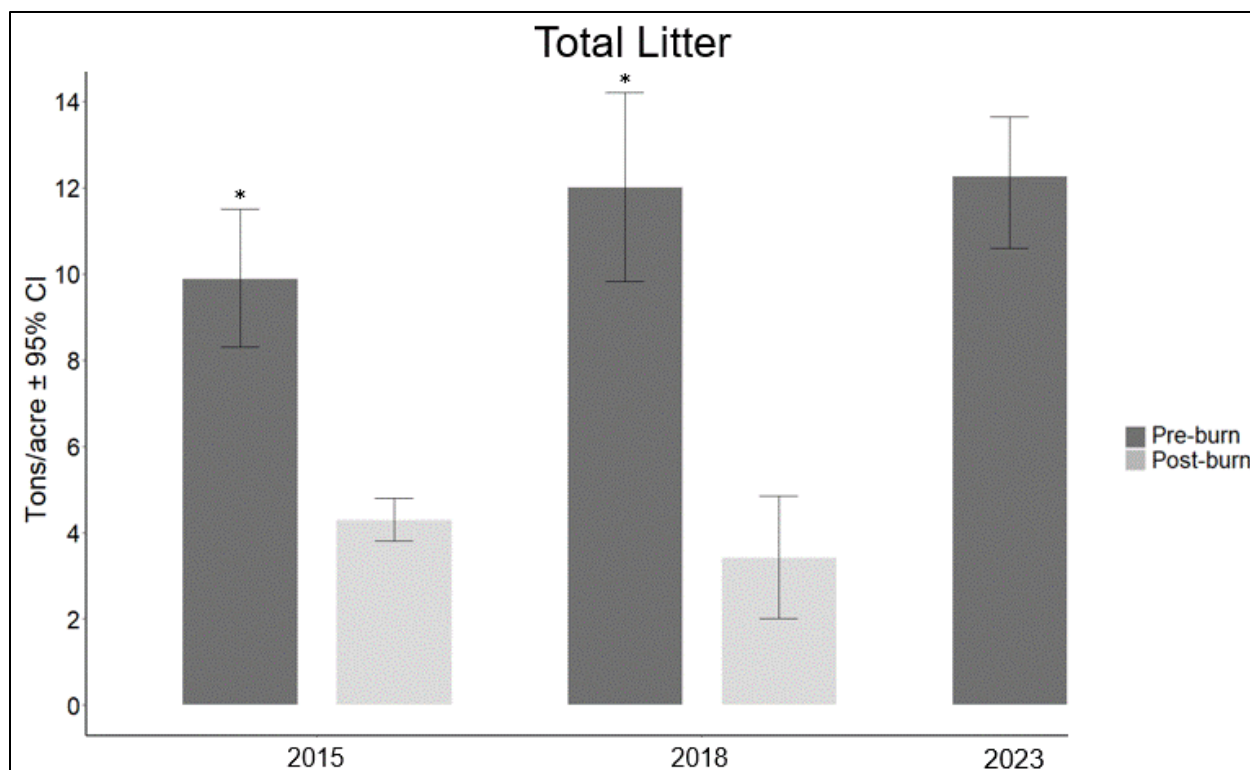


Figure 1.12. Bar graph comparing total litter consumption and recovery from two prescribed burns at Howe Natural Resources Education Center, Manhattan, Kansas. Prescribed burns occurred in 2015 and 2018, there was not a burn from 2018 to 2023. Values are combined means from burn only and burn and thin areas. Asterisks above error bars indicate significance within year.

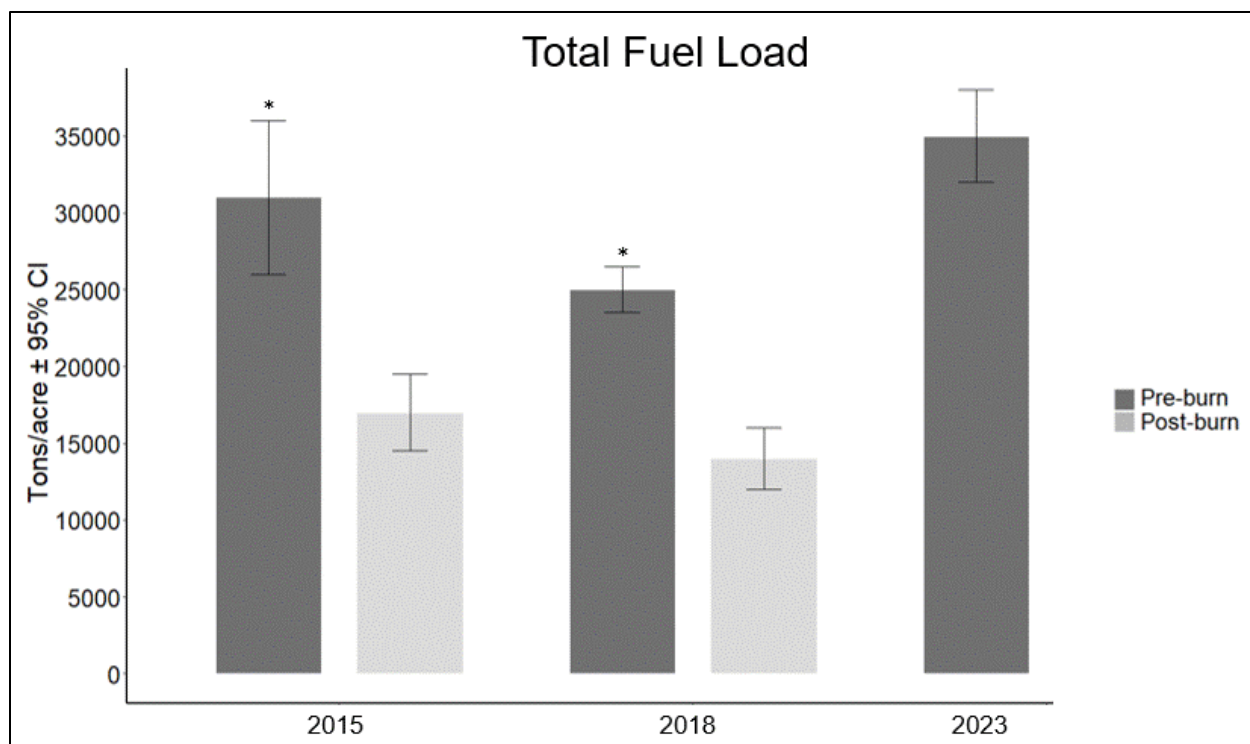


Figure 1.13. Bar graph comparing total fuel load consumption and recovery from two prescribed burns at Howe Natural Resources Education Center, Manhattan, Kansas. Prescribed burns occurred in 2015 and 2018, there was not a burn from 2018 to 2023. Values are combined means from burn only and burn and thin areas. Asterisks above error bars indicate significance within year.

Chapter 2 - White-tailed deer responses to prescribed fire and thinning in a Kansas woodland

Abstract

Maintaining open canopy forests is important to maintain diversity within the understory to meet nutritional requirements for White-tailed deer (*Odocoileus virginianus*) in a hardwood system. Techniques such as mechanical thinning coupled with prescribed fire are often used to promote understory development. Although these treatments have been frequently assessed for regeneration purposes, deer responses to these treatments are not commonly evaluated, specifically on a seasonal gradient. To understand deer responses to two mechanical thinnings and two prescribed fires, we deployed 24 camera traps across a 90-acre oak dominated woodland that contained four different treatments: Burn Only, Thin Only, Burn and Thin, and Control. We monitored deer activity for 18 months and recorded weekly photographic rates for each treatment as a measure of activity. We also examined age and sex class differences in activity among seasons. We found that during the duration of our study deer activity was highest in the Burn Only and Control areas. However, does used all areas that were burned more than Control or Thin Only areas. Furthermore, our combined age and sex class category “all-deer”, and “bucks” category were most active during the breeding season and does and fawns did not follow a similar trend in activity during this season. We recommend low intensity prescribed fires coupled with canopy reductions to increase food and cover availability for deer, but more specifically for does and fawns during the fawning and lactation period.

Introduction

In the United States, oak (*Quercus* spp.) represents ~46% of forest landcover (McWilliams et al. 2002) and offers a wide variety of benefits for wildlife including cover and forage from hard-mast production and high-quality browse. Historically, periodic fires played a key role in the development of oak forests (Shumway et al. 2001, Lafon et al. 2017). Native Americans used fire to modify landscapes, and to manage wildlife habitat to make wildlife movements more predictable (Abrams and Nowacki 2008). Prior to European settlement of North America, millions of acres were burned every 3-10 years (Dey et al. 2022). In the early 1900s, fire became viewed as destructive to wildlife habitat, and fear of wildfire resulted in fire suppression. The loss of fire as a natural disturbance sparked the conversion of open, fire-maintained forest to closed canopy forest. Efforts to restore and regenerate oak forest led to the investigation of prescribed fire as an effective management tool. Many decades of prescribed fire research in oak forests show that fire can encourage oak regeneration if used appropriately in combination with other silvicultural practices such as thinning (Knapp et al. 2009, Brose et al. 2014, Dey et al. 2017). Since the 1960s, prescribed fire has become accepted as a necessary management tool that is used by private, state, and federal agencies.

Managers often use prescribed fire, herbicides, and selective removal of target species (i.e. mechanical thinning) to restore undesired, closed canopy forest back to oak dominated woodlands. Thinning requires targeting and removing individual trees and often alters species composition by reducing canopy cover, which increases sunlight to the understory and encourages germination of early successional vegetation. This results in a higher abundance of shrubs, and herbaceous vegetation which benefit wildlife. Closed-canopy forests are generally poor habitat for species requiring well-developed understory (Johnson et al. 1995, Edwards et al.

2004, Jackson et al. 2007), and are less receptive to fire because of cooling and dampening of the leaf litter that results from mesophication (Nowacki and Abrams 2008, Abrams 2016). Oaks have developed characteristics that allow them to tolerate fire, including thick bark, deep taproots, an ability to resprout after being top killed, and the ability to heal from fire scars on the stem. Together, these adaptations make oaks dominant in most frequently burned woodlands (Choung et al. 2004).

Burning consumes thatch layers allowing sunlight to contact the topsoil and increase germination of early successional species, including pokeweed (*Phytolacca americana*), greenbrier (*Smilax spp*), Desmodiums (*Desmodium spp.*), showy partridge pea (*Chamaecrista fasciculata*), and prickly lettuce (*Lactuca serriola*) (Harper 2019). Additionally, burning maintains open-forest conditions by removing aggressive, fire intolerant species, resulting in an open canopy preferred for oak regeneration. These open forest conditions are ideal for promoting food and cover, specifically for white-tailed deer (*Odocoileus virginianus*, hereafter ‘deer’). Wildlife managers often pair burning and thinning to reduce tree density and increase the production of early successional species to improve deer habitat.

Nutritional and habitat requirements must be understood when managing for optimal deer habitat. Habitat is composed of resources required by deer and includes food, cover, water, and space. Three principles are important when managing habitat for deer 1.) optimal habitat consists of a mosaic of areas dominated by woody plants interspersed with areas dominated by herbaceous plants. 2.) Heterogeneous landscapes are more beneficial than homogeneous landscapes which can be targeted using techniques such as burning and thinning. 3.) With these principles in mind plant communities should be managed to allow deer to sustain positive energy balance through sufficient food supply and thermal cover (Fulbright and Ortega-Santos 2013).

Habitat use can change seasonally and tracks forage availability and/or cover (Pauley et al. 1993) which both can be influenced by land managers applying proper silvicultural techniques. Few studies, however, have assessed seasonal changes in habitat use by deer. Lashley et al. 2015 reported that lactating females select unburned areas (>1yr-since-fire) and avoid areas recently burned but selected burned areas as time since burn increased. This is likely because of the immediate reduction in cover and food availability after prescribed fires and underscores that habitat heterogeneity is needed to increase seasonal habitat quality. Cherry et al. 2017 investigated effects of time since fire on the selection of fawn rearing areas. They concluded that deer selected woodlands with greater time since fire and avoided recently burned areas, potentially sacrificing food availability for concealment cover during this season. Habitat management typically involves manipulating vegetation by applying prescribed fire, timber stand improvement (TSI), herbicide application, supplemental food plots, or a combination of these techniques. Fire changes plant communities by decreasing dominance of fire intolerant species and promoting fire tolerant species. Predictions of how plant species will respond to fire depend on a combination of factors including fire regime, and the species strategy for survival after a fire (Pyke et al. 2010). Therefore, fire can strategically be used to promote a desired plant community for deer, and further target undesired tree species by changing fire regime and seasonality to provide a preferred habitat for deer. Moreover, TSI combined with low intensity prescribed fire with short term fire intervals has shown a significant increase in available nutrition and cover in hardwood systems (Lashley et al. 2011). A single acre of open canopy forest can easily provide 200-600 lbs. of forage for deer, which will drastically reduce once the forest has developed a closed canopy (Brooke et al. 2021). Therefore, the large amount

of available forage provided in open canopy forest highlights the importance of prescribed burning and TSI for forage and cover availability.

Habitat use can differ between demographic classes of deer due to differences in resource needs. Depletion of adequate food resources during gestation periods can have multigenerational effects on body mass and antler potential which reinforces the importance of quality nutrition during gestation (Monteith et al. 2009). Furthermore, summer lactation demands high quality forage for females and is the most stressful period for deer (Hewitt 2011), leading them to select habitat best suited for their nutritional needs. Prescribed fire promotes germination of early successional species that have higher nutrient quality and are more palatable than previous growth of perennial plants (Jones and Case 1990, Leigh et al. 1991), potentially leading to positive effects on physical condition of females and milk quality during lactation. Consequently, growing season fires (i.e. May through July) may reduce food and cover availability during lactation which could cause females to be more sensitive to seasonal fires than males. This is due to the high demand of dense cover and food by lactating females (Kie and Bower, 1999, Naugle et al. 1997), which would be removed by a growing season fire.

Although deer responses to fire are well understood (e.g., Ivey and Causey 1984, Meek et al. 2008, Lashley et al. 2015) their response to multiple management actions in oak woodlands is less clear. Our objectives were to assess the effects of two mechanical thinning treatments followed by two prescribed fires on deer activity in an oak woodland delineated by sex, age class, and biological season. We hypothesized biological season will influence activity among treatments, specifically females and males will have the highest activity in burn and thin treatments during lactation and antler growth season. We also predict burn and thin treatments would have the highest activity for all age class and sex categories year-round due to increased

forage availability and cover, whereas the lowest activity would occur in control treatments caused by decreased forage availability and undesired cover under the closed canopy.

Methods

Study Area

Our study was conducted at the Howe Natural Resource Education Center, owned by Kansas State University (GPS location: 96°40'31.316"W, 39°19'37.983"N), a 90-acre (58.68 ha) woodland dominated by chinkapin oak (*Quercus muehlenbergii*), mixed with hackberry (*Celtis occidentalis*), American elm (*Ulmus americana*), eastern redcedar (*Juniperus virginiana*), redbud (*Cercis canadensis*), bitternut hickory (*Carya cordiformis*), bur oak (*Quercus macrocarpa*), and black walnut (*Juglans nigra*). Major understory vegetation was composed of wild raspberry (*Rubus moluccanus*), prickly ash (*Zanthoxylum Americanum*), buckbrush (*Symphoricarpos orbiculatus*), Virginia creeper (*Parthenocissus quinquefolia*), pokeweed (*Phytolacca americana*), greenbrier (*Smilax spp*), and tree seedlings. Only the oak-dominated area of the property was used due to greater densities of eastern redcedar on a portion of the study area. Soils consisted of clime silty loam, with 20-40% slopes (USDA NRCS 2017).

Experimental Design

A randomized complete block design was used for the study site. We used a two-way split plot factorial design with two levels of burn treatments (burned and unburned) and two levels of thin treatments (thinned and non-thinned). Natural drainages were used as boundaries, when possible, for convenience of fire breaks. Slopes are distributed from 20% to 40% (USDA NRCS 2017) and elevations range between 335ft (102 m) to 402ft (123 m). The project design

by Galgamuwa et al. (2018) included dividing the study area into three large blocks based on topography. Each block contained four compartments; each compartment randomly had one treatment assigned. Treatments were burn (B), thin (T), burn & thin (BT), control (C). Each treatment had 3 replicates, totaling 12 compartments, each compartment ranging from 6 to 10 acres (2.43-4.05).

Treatments

The forest inventory pretreatment in 2014 indicated all compartments were fully stocked (stocking between 60% and 100%) except one compartment was overstocked (>100%), and the average basal area was 100 ft²/acre and 162 trees per acre, respectively. The forest is characterized as closed a canopy, late successional forest with the average tree 72 years of age (Galgamuwa et al 2018). The first thinning in January 2015 was set to maintain stocking of 55% to 70 % appropriate for oak regeneration (Hanberry et al. 2017). Trees were thinned to 25 trees per-acre (TPA) (62 TPha), respectively, and the thinning prescription targeted removal of Eastern redcedar, hackberry, and American elm. Saplings were thinned by 50 stems per-acre (124 stems per ha) of eastern redcedar, hackberry, American elm, and eastern redbud. We classified trees as stems with diameter breast height (dbh) greater than ≥ 5 in (12.7 cm) and saplings with stems from 1 - 4.9 in (2.54 to 12.45 cm). Saplings were felled and chemically treated with a mix of 25% Garlon (distributed by Dow AgroSciences, Zionsville, Indiana) and 75% diesel fuel to control resprouting. Trees were single girdled and treated with the same mixture. Desired mast producing species such as oak, hickory, and walnut were favored in the thinning process. A second thinning was conducted in February 2018 and procedures were

similar to the first thinning, except the prescription varied per compartment according to the compartment stocking to ensure the desired stocking of 55% to 70%.

Prescribed burns were conducted by the Kansas Forest Service and Kansas State University staff. The first burn during April 2015 was a dormant season fire with air temperature of 75°F, 33% relative humidity, and a 20ft wind speed of 4-6 mph Galgamuwa et al. 2019. Fire behavior was mild with flame lengths 6- to 12- in (15.2- 30.5cm) and spread of 5- to 10-ft/min (1.52- 6.1 m/min). The second burn occurred in May 2018, and was later than originally planned because the fuel was too wet from spring rains. Air temperature was 75 °F with relative humidity of 50%, and a wind speed of 7 mph (Simões et al. 2019), and the woody species were starting to leaf out.

Habitat Use and Photo Processing

We used deer activity (weekly photographic rate) as an index to habitat use (Staudenmaier et al. 2021). To determine deer activity, we deployed two camera traps per compartment (6 cameras per treatment, 24 total cameras) by randomly selecting two existing study plots and ensuring they were at least 200 meters apart to maintain temporal independence among photos at different cameras (Parsons et al. 2017). Our cameras were deployed from July 2022 to January 2023. We used Bushnell (Trophy Cam HD; Bushnell Outdoor Products, Overland Park, Kansas) attached to a stake 0.5 m off the ground and set for 30 second delay. Cameras were oriented north or south to avoid solar interference. Herbaceous vegetation was removed in the field of view to limit obstruction. Camera trap locations were permanent throughout the entire study period and batteries and memory cards were replaced on a two-week rotation.

We used Colorado Parks and Wildlife photo warehouse (Colorado Parks and Wildlife Photo Warehouse 4.0, Colorado Parks and Wildlife, Fort Collins, CO, USA) and manually examined photos from each camera. All individuals in each detection image were demographically classified as: 1) all-deer, 2) buck, 3) doe, and 4) fawn. Deer that we could not identify were categorized into an ‘unknown’ category and only included in the “all deer” analyses. Any antlered deer was categorized as “buck”. Antlerless deer that did not show characteristics of a fawn or shed buck were categorized as “doe”. Fawns were classified as deer <1 year of age. We used spots, body size, chest girth, body length, and head length to identify fawns as these characteristics are useful to determine the age of a fawn when measuring hoof growth is not possible (Sams et al. 1996) . To ensure temporal independence between photos, we only scored images of deer separated by 15 minutes (Gallo et al. 2022). Each photograph separated by 15 minutes and including deer was classified as an event. Thus, in group sizes >1, a single picture could yield >1 event (Dykes et al. 2018). For our response variable, we used weekly photographic rate (‘PR’ hereafter), as a measure of activity. We considered treatment and season fixed effects. We analyzed 4,312 photos of does, 1,940 photos of bucks, 312 photos of fawns, and 1,575 images were classified as unknown, totaling 8,193 independent photos of deer.

Data Analysis

To determine activity within treatments by biological season, we categorized four seasons: winter (January 1 – March 14 [weeks 1-11]), winter-spring transition (March 15- May 14 [weeks 12-19]), fawn rearing and antler growth (May 15- August 30 [weeks 20-35]), and breeding (September 1 – December 31 [weeks 36-52]) (Kilpatrick and Spohr 2000). Statistical analyses were conducted in R (R version 4.2.2; R Core Team 2022) and functions in the base

packages were used to evaluate activity based on sex and age class using ANOVA. We used model selection based on Akaike Information Criterion corrected for small sample size (AICc) to identify the ANOVA models that best described deer activity in our treatments and among seasons (Burnham and Anderson 2002). Candidate model sets for deer activity included the effects of treatment, biological season, a constant model, and models with additive (+) and interactive (x) effects. We made pairwise comparisons of group means from the top models using t-tests. Means were considered statistically different at an alpha of $p < 0.05$. Treatment models included our four treatments (burn only, thin only, burn and thin, and control), and season models included our four seasons (winter, winter-spring transition, fawn rearing and antler growth, and breeding).

Results

All Deer

Our top ranked ANOVA model for the all-deer category was a main effects additive model with the effects of treatment ($F_{(3, 1274)} = 7.04$, $p < 0.05$) and season ($F_{(3, 1274)} = 35.63$, $p < 0.05$; Table 2.1). During our 1.5-year study, our all-deer category used Control and Burn Only areas (PR = 8.8, 8.46, $p < 0.05$) more than Thin Only and Burn and Thin areas (PR = 6.6, 6.10, respectively; Figure 2.2). Therefore, deer used areas that were thinned less than Burn Only and Control areas during our study period. When we assessed activity during within our four biological seasons, deer activity was higher during the Winter and Breeding seasons (PR = 7.9, 10.1, $p < 0.05$, respectively) than the Winter-Spring Transition, and Fawn Rearing and Antler Growth seasons (PR = 4.1, 4.6, $p < 0.05$, respectively). There was not a difference in activity between the Winter-Spring season and the Fawn Rearing and Antler Growth season.

Does

Our top ANOVA for doe activity was a two-way interaction model between treatment and season ($F_{(3,984)} = 3.10$, $p < 0.05$; Table 2.2). In the Winter season, does used Control and Burn only areas more than Burn and Thin areas ($p < 0.05$, $p < 0.05$; Figure 2.3). During the Fawn Rearing and Antler Growth season, does were using Burn Only and Burn and Thin areas more than the Control areas (PR = 3.73, 3.44, 2.51, $p < 0.0$, $p < 0.05$, respectively). During the winter spring transition, does used Burn only more than Thin only (PR = 3.5, 2.1, $P < 0.05$). Does used Control and Burn Only areas more than Burn and Thin areas during the Breeding season (PR = 7.9, 7.42, 5.05, $p < 0.05$, $p < 0.05$, respectively).

Bucks

There were two competing models predicting buck activity between season and treatment because the additive model using treatment and season, and the one- way season model were within two AIC values (Table 2.3). Overall, bucks did not have as dramatic of a shift in activity patterns across treatments as our other categories did. During our study period, bucks did not show significance among treatments. However, when we assessed seasonal activity, bucks had higher activity during the breeding season (PR = 4.9, $p < 0.05$; Figure 2.4) than any other season. This was the only significant activity for bucks during our study period

Fawns

The top ranked model for fawns was a main effect additive model with the effects of treatment ($p < 0.05$, Df = 3, $F = 3.72$) and season ($p < 0.05$, Df = 3, $F = 5.36$; Table 2.4). During the duration of our study period, fawns used Control areas more than Burn and Thin areas ($p < 0.05$,

PR = 2.0, 1.5, respectively; Figure 2.5). Other treatments did not have an effect on fawn activity during the duration of our study period. Activity from fawns was lower during the Breeding season than the Winter, and Winter-Spring transition seasons (PR = 1.65, 1.20, 1.42, respectively, $p < 0.05$).

Discussion

Our 1.5-year examination of White-tailed deer activity across forestry treatments resulted in three major findings. First, deer activity varied significantly among treatments during the duration of our study period. The all-deer category was more active in the Burn Only and Control areas than Thin Only and Burn and Thin areas over our entire study period. Therefore, deer were using areas that did not contain thinning. Second, doe activity among treatments varies significantly based on season. Does were most active in Burn Only and Control areas over course of the study period, but our two-way interaction model between season and treatment indicated their activity shifted Fawn Rearing and Antler Growth season to treatments managed with prescribed fire. Third, deer activity varied among seasons. The all-deer category and bucks were more active during the Breeding season than any other season.

Deer benefit from vegetation responses caused by burning. Fire influences vegetation by releasing nutrients and stimulating new growth. These vegetation responses result in an increase in forage production, forage availability, and palatability after a fire (Thill et al. 1987, Proffitt et al. 2019) and doe activity patterns in our study correlated with these vegetation responses during the growing season. Our findings that doe activity changes seasonally within different forestry treatments were consistent with previous work (Lashley et al. 2015). However, this trend was not consistent across all categories as we hypothesized. Does were the only category during the Fawn Rearing and Antler Growth season to use Burn Only and Burn and Thin areas more than

Control areas. On the other hand, treatment did not have an effect on buck activity, but their activity during the Breeding season was higher than any other season. The conclusion from Root et al. 1988 stating deer seek dense cover during the hunting season was true for only does in our study. Although over the course of our study, the all-deer category was using the Burn Only and Control areas. These areas have more cover because they were not thinned, deer may have been using there areas because of the cover, similar to findings from Root et al. 1988.

For does, thinning in combination with fire was important during the Fawn Rearing and Antler Growing season. Does were avoiding thinned areas during the Breeding and Winter season and using Burn Only and Control areas, and activity patterns in these areas were very similar. This partially agrees with our second hypothesis that Burn and Thin areas would result in the highest deer activity over the entire study period. Thinning did not have as great an effect on deer activity as we expected. The large amount of felled tree debris after thinning could have impeded deer movement. Consequently, deer used Burn Only and Control areas more during our study period. In a closed canopy forest, fire intensity must be great enough to kill a portion of the overstory for fire alone to have an ample effect on wildlife species because it does not result in enough sunlight penetration to stimulate a significant understory response (Harper et al. 2016). Therefore, thinning is often coupled with fire to increase sunlight to the understory while stimulating early successional species via fire. In our study, does used Burn and Burn and Thin areas more than Control areas during the Fawn Rearing and Antler Growth season. This increased activity likely reflects the abundance of food and hiding cover in the understory that was present during the growing season in these treatments.

Our detection rate of fawns was low relative to doe detections. Fawns were more active in Control areas than Burn and Thin areas over the course of our study period. Within biological

season, fawns were less active during the breeding season compared to the Winter and Winter-Spring transition season. Although does used Burn Only and Burn and Thin areas more than Control during Fawn Rearing and Antler Growing season, this trend was not reflected in fawn activity. The tall, thick vegetation in these areas could have limited our ability to detect fawns, resulting in a lower detection probability in the areas that were thinned. Fawns likely followed similar activity patterns as does during the fawn rearing season but remained undetected due to vegetation obstruction. Fawns did not have any significant change in activity during the Winter and Winter-Spring transition seasons which was similar to the activity patterns of does.

Fire frequency is typically considered the driving factor for flora and fauna responses at both the landscape and local scale (Frost 1998, Nowacki and Abrams 2008). Fire intervals of three to five years are recommended to maintain soft mast and forage for white-tailed deer after thinning (Lashley et al. 2011). Our study site has been burned twice on a four-year fire return interval and was last burned four years prior to the start of our data collection. A shorter fire return interval, 2-3 years for example, may be needed to continue to stimulate early successional species and reduce a portion of the mid-story canopy that could have increased after the last thinning in 2018. However, caution must be used when lowering the fire return interval, because of the immediate reduction of cover in the same year as fire (McCord et al. 2014). Lashley et al. 2015 reported deer were avoiding newly burned areas potentially due to predation risk from coyotes (*Canis latrans*), but activity in these areas increased with years since fire.

Our thinning prescription was targeted to increase oak regeneration, which may differ from a thinning prescription specifically for deer habitat improvement based on forest maturity and composition. Thinning for oak regeneration consists of removing competing tree species and targeting specific light conditions adequate for oaks to germinate and grow. These “competing

species” such as elms, hackberry, and honey locusts are removed and treated to avoid resprouts when thinning for oak regeneration. Foliage from these competing species such as Juvenile leaves and resprouts after being felled are considered choice foods for deer (Bidwell et al. 2007). Our thinning prescription aimed to reduce the forest density to a basal area of 60ft²/ac, which is identical to the recommended basal area to meet White-tailed deer habitat requirements of 40-60ft²/ac (Bidwell et al. 2007, Masters and Stewart 2020). When managing deer, techniques such as coppicing, hinge cutting, and edge feathering are often used during thinning to increase forage availability and cover. These techniques were not used during the thinning prescription because they do not contribute to enhancing oak regeneration, which was the initial objective of the study. If these techniques were used during the thinning prescription, they may have provided more cover and browse, therefore increasing deer activity in these areas.

The results of our research demonstrate that prescribed fire is beneficial for deer during the growing season. Habitat requirements may differ between sex classes, and bucks are less likely to be dependent on cover during the summer (Kie and Bowyer, 1999, Naugle et al. 1997). Our results show does were more active in areas that were burned, likely seeking cover and palatable vegetation, during the growing season. We suggest habitat quality can be improved for deer by implementing periodic fires coupled with thinning using techniques such as coppicing and hinge cutting. We recommend fire regimes of 2-5 years for woody understory development and maintenance of mature hardwoods, and landscape heterogeneity (Lashley et al. 2014). Further research needs to be conducted immediately after fire through multiple years post fire to further understand deer responses on a seasonal gradient.

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Table 2.1. Candidate models and model statistics for all-deer category of White-tailed deer activity at Howe Natural Resource Center, Kansas, United States, from July 2022 to January 2024. Forestry treatments included burn only, thin only, burn and thin, and control. Seasons were: (winter: January 1 – March 14, winter-spring: March 15 – May 14, Fawning: May 15 – August 30, breeding: September 1 – December 31).

All Deer	Model Statistics					
Model Structure	K	AICc	Δ AICc	AICc.wt	Cm.wt	LL
Treatment + Season	8	9126.81	0	0.88	0.88	-4555.35
Treatment x Season	17	9130.84	4.04	0.12	1.0	-4548.18
Season	5	9145.01	18.21	1.0	1.0	-4567.48
Treatment	5	9226.96	100.16	1.0	1.0	-4608.46
Constant	2	9241.94	115.13	1.0	1.0	-4618.96

Table 2.2. Candidate models and model statistics for does category of White-tailed deer activity at Howe Natural Resources Education Center, Kansas, United States, from July 2022 to January 2024. Forestry treatments included burn only, thin only, burn and thin, and control. Seasons were: (winter: January 1 – March 14, winter-spring: March 15 – May 14, Fawning: May 15 – August 30, breeding: September 1 – December 31).

Does	Model Statistics					
Model Structure	K	AICc	Δ AICc	AICc.wt	Cm.wt	LL
Treatment x Season	17	6039.23	0	0.99	0.99	-3002.30
Treatment + Season	8	6049.52	10.29	0.01	1.0	-3016.69
Season	5	6069.32	30.09	0	1.0	-3029.63
Treatment	5	6147.92	108.69	0	1.0	-3068.93
Constant	2	6162.34	123.11	0	1.0	-3079.16

Table 2.3. Candidate models and model statistics for does category of bucks White-tailed deer activity at Howe Natural Resources Education Center, Kansas, United States, from July 2022 to January 2024. Forestry treatments included burn only, thin only, burn and thin, and control. Seasons were: (winter: January 1 – March 14, winter-spring: March 15 – May 14, Fawning: May 15 – August 30, breeding: September 1 – December 31).

Bucks	Model Statistics					
Model Structure	K	AICc	Δ AICc	AICc.wt	Cm.wt	LL
Treatment + Season	8	3419.17	0	0.63	0.63	-1701.46
Season	5	3420.23	1.06	0.37	1.0	-1705.06
Treatment x Season	17	3430.72	11.55	0	1.0	-1697.82
Constant	2	3479.96	60.79	0	1.0	-1737.97
Treatment	5	3481.19	62.02	0	1.0	-1735.54

Table 2.4. Candidate models and model statistics for fawns category of White-tailed deer activity at Howe Natural Resources Education Center, Kansas, United States, from July 2022 to January 2024. Forestry treatments included burn only, thin only, burn and thin, and control. Seasons were: (winter: January 1 – March 14, winter-spring: March 15 – May 14, Fawning: May 15 – August 30, breeding: September 1 – December 31).

Fawns Model Structure	Model Statistics					
	K	AICc	Δ AICc	AICc.wt	Cm.wt	LL
Treatment + Season	8	739.85	0	0.77	0.77	-361.61
Season	5	742.41	2.56	0.22	0.99	-366.07
Treatment	5	749.50	9.64	0.01	1.0	-369.62
Treatment x Season	17	750.85	10.99	0	1.0	-357.01
Constant	2	753.79	13.93	0	1.0	-374.87

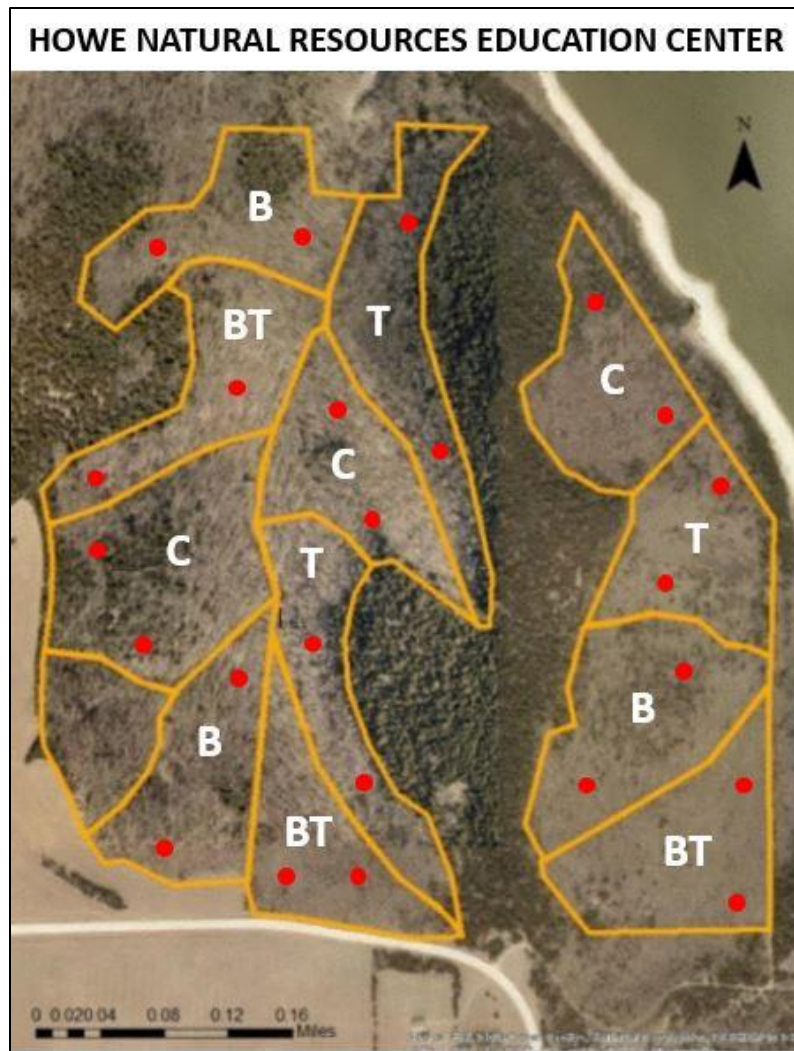


Figure 2.1. Experimental layout of study site showing camera trap locations (red dots) and forestry treatments at Howe Natural Resources Education Center, Manhattan, Kansas, United States. Treatments include “Burn Only” (B), “Thin Only” (T), “Burn and Thin” (BT), and “Control” (C). Plots range between 6-10 acres, and treatment occurred in 2015 ad 2018. In total, 24 camera traps were places throughout the study area (red dots).

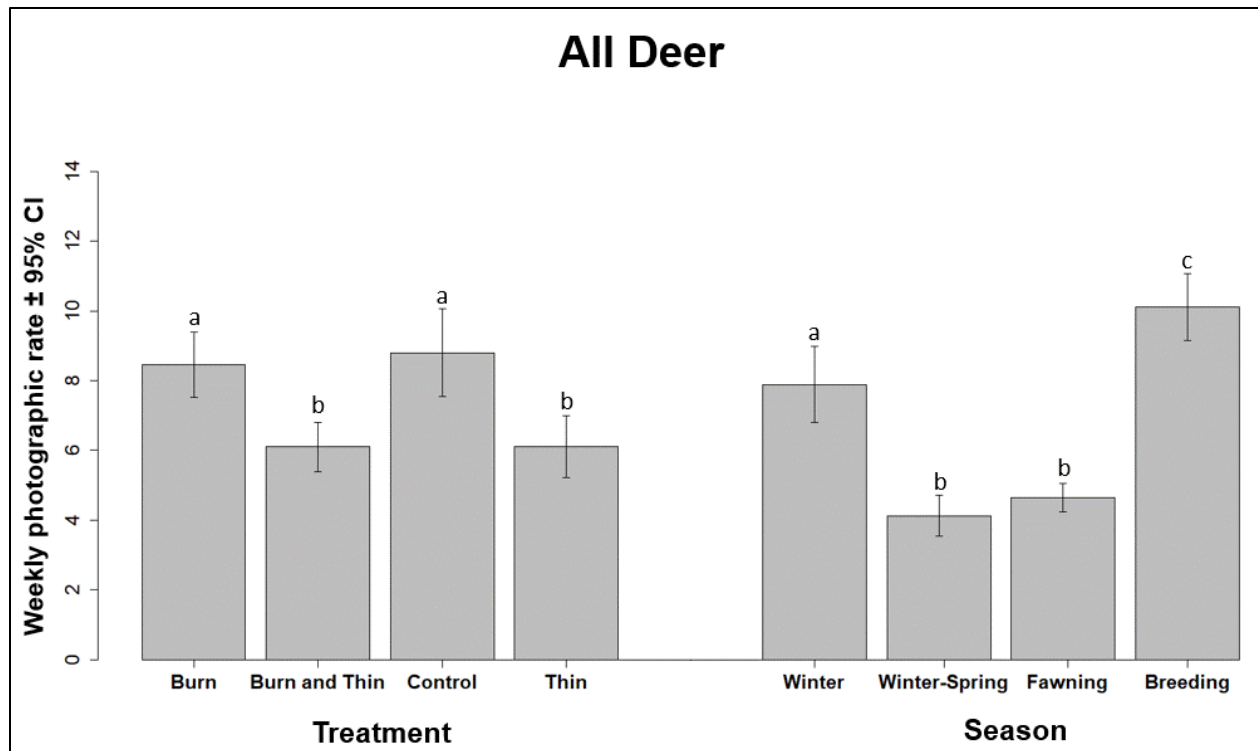


Figure 2.2. Additive model bar graph for weekly photographic rate of White-tailed deer within forestry treatments (left) at Howe Natural Resources Education Center and biological season (right) (winter: January 1 – March 14, winter-spring: March 15 – May 14, Fawning: May 15 – August 30, breeding: September 1 – December 31) in Kansas, United States, from July 2022 to January 2024. Comparisons are made between treatments and between seasons.

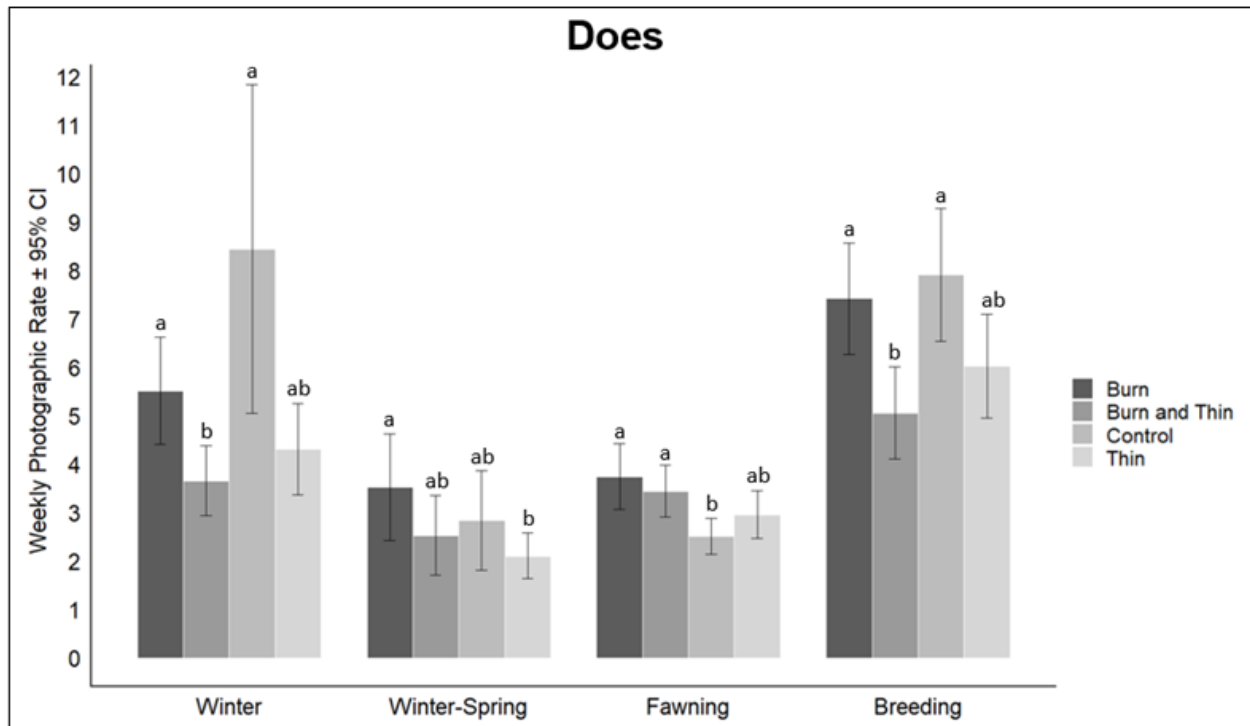


Figure 2.3. Two-way interactive model of weekly photographic rate of doe White-tailed deer within forestry treatments and biological season (winter: January 1 – March 14, winter-spring: March 15 – May 14, Fawning: May 15 – August 30, breeding: September 1 – December 31) at Howe Natural Resources Education Center, Kansas, United States, from July 2022 to January 2024.

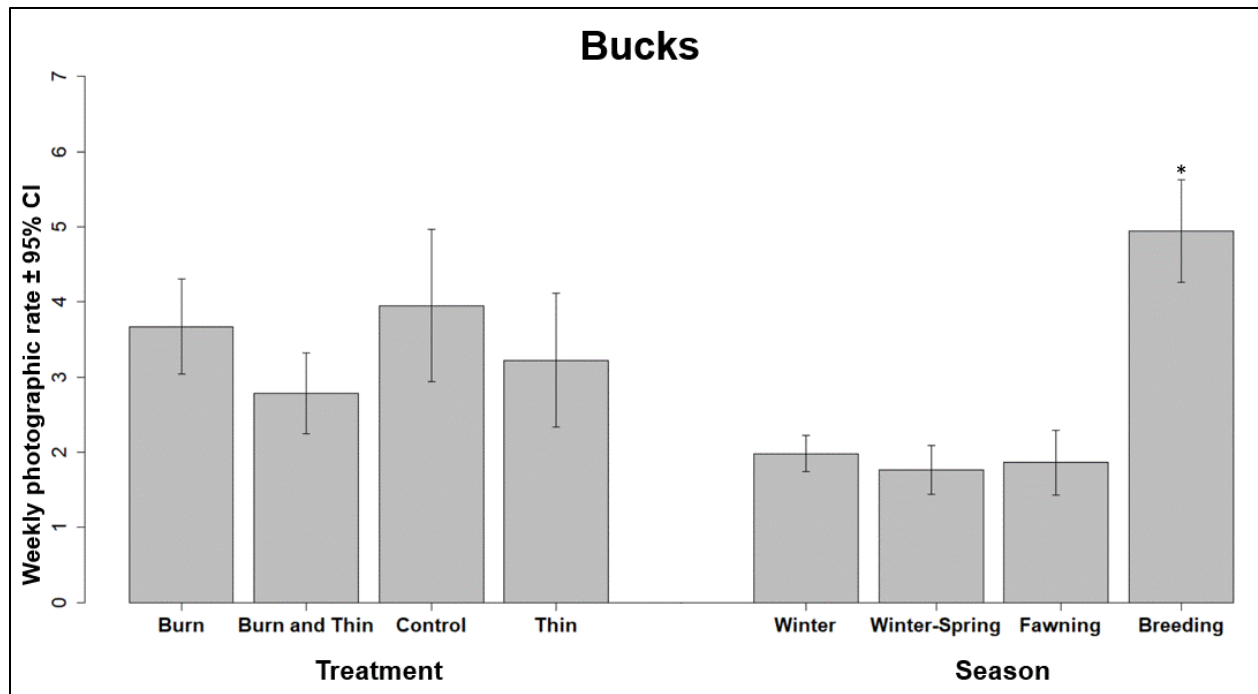


Figure 2.4. Additive model bar graph for weekly photographic rate of buck White-tailed deer within forestry treatments (left) at Howe Natural Resources Education Center and biological season (right) (winter: January 1 – March 14, winter-spring: March 15 – May 14, Fawning: May 15 – August 30, breeding: September 1 – December 31) in Kansas, United States, from July 2022 to January 2024. Comparisons are made between treatments and between seasons.

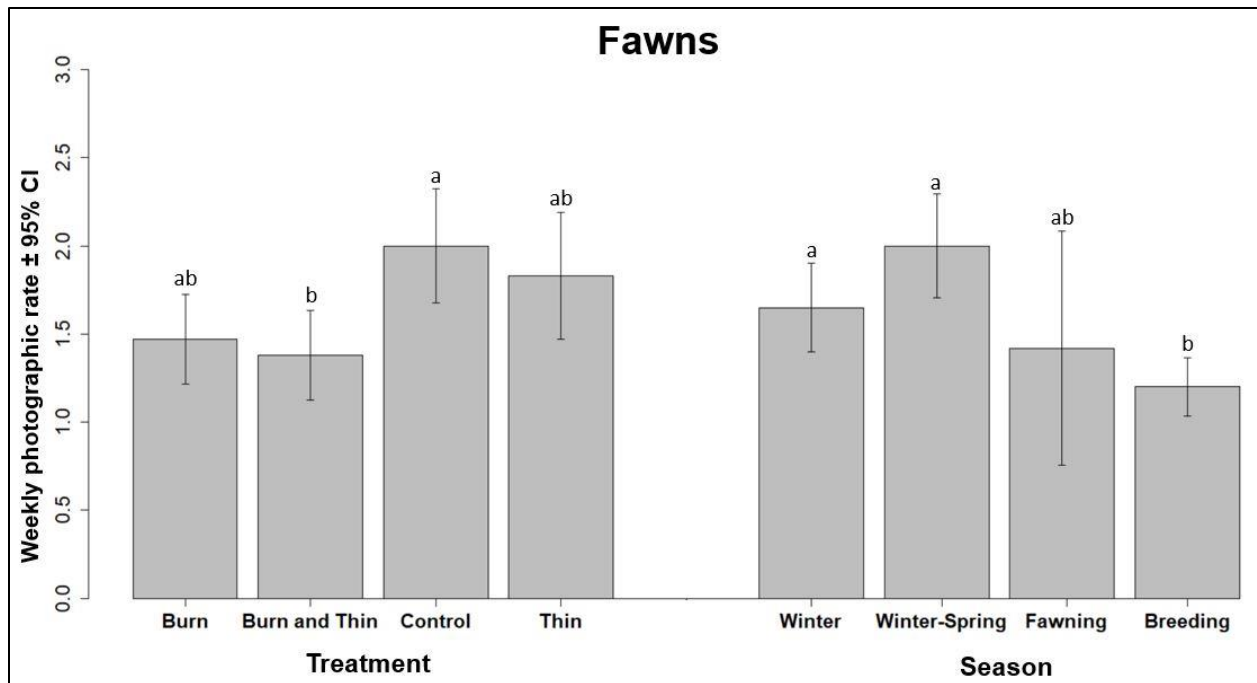
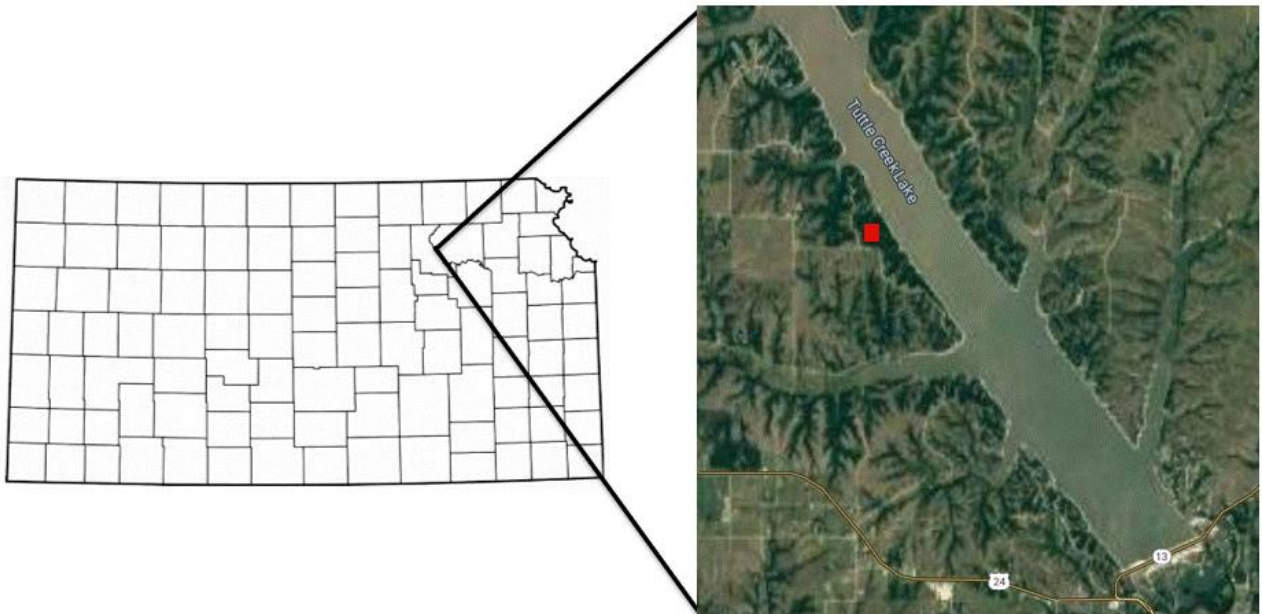


Figure 2.5. Additive model bar graph for weekly photographic rate of fawn White-tailed deer within forestry treatments (left) at Howe Natural Resources Education Center and biological season (right) (winter: January 1 – March 14, winter-spring: March 15 – May 14, Fawning: May 15 – August 30, breeding: September 1 – December 31) in Kansas, United States, from July 2022 to January 2024. Comparisons are made between treatments and between seasons.

Appendix A - Oak Regeneration Pictures



Appendix Figure A.1. Study area location of Howe Natural Resources Education Center in Riley County, Kansas. Red square indicates 145-acre study area location. The study area is divided into 12 compartments each assigned a treatment. Burn only, thin only, burn and thin, and control. There are three replicates of each treatment, totaling 12 compartments.



Appendix Figure A.2. Sign located at Howe Natural Resources Education Center. Picture taken by Pahodha Galgamuwa.



Appendix Figure A.3. Part of the Howe Natural Resources Education Center project was funded by the National Wild Turkey Federation (NWTF) funds. Prescribed burns were organized by the Kansas Forest Service. Picture taken by Pabodha Galgamuwa.



Appendix Figure A.4. Tree girdled and treated with Garlon and diesel mixture during thinning operations at the Howe Natural Resources Education Center, Manhattan, Kansas. Thinning was prescribed to remove 25 trees per acre of Eastern redcedar (*Juniperus virginiana*), American elm (*Ulmus americana*), hackberry (*Celtis occidentalis*), and Eastern redbud (*Cecis Canadensis*); and 50 sapling per acre of Eastern redcedar, American elm, hackberry and Eastern redbud. Photo taken by Pabodha Galgamuwa. 50 stems of saplings/acre of American elm, Eastern redbud, Eastern redcedar and hackberry



Appendix Figure A.5. Smaller saplings were felled and treated with Garlon and diesel mixture. Photo taken by Pabodha Galgamuwa.



**Appendix Figure A.6. Fire behavior of the 2015 burn near a data collection point (T post).
Photo by Pabodha Galgamuwa.**



Appendix Figure A.7. Low intensity fire behavior of the 2015 burn. Photo by Pabodha Galgamuwa.



Appendix Figure A.8. Tall flames in a burned and thinned area in 2015. Photo by Pabodha Galgamuwa.



Appendix Figure A.9. Kansas Forest Service firefighter in a burned and thinned area in 2015. Flames were up to 20 feet tall on thinned Eastern redcedars. Photo by Pabodha Galgamuwa.



Appendix Figure A.10. Burns were successful at consuming the fuel in 2015. Photo by Pabodha Galgamuwa.



Appendix Figure A.11. Chinkapin oak (left) and Eastern redbud (right) sprouting after being top killed during a burn. Photo by Pabodha Galgamuwa.



Appendix Figure A.12. Burn attempt in May 2023. The vegetation was green, and the fuel load was too wet.



Appendix Figure A.13. May 2023 burn attempt.



Appendix Figure A.14. Measuring dead woody debris diameter in a thinned area for fuel load.



Appendix Figure A.15. Measuring litter depth.



Appendix Figure A.16. Collecting seedling data at data collection point.



Appendix Figure A.17. Identifying seedling species at data collection point.

Appendix B - White-tailed deer activity



Appendix Figure B.1. Changing SD cards and batteries on a on a two-week rotation for camera traps.



Appendix Figure B.2. Camera setup 0.5 meters off the ground in a Burn Only area near a preexisting t-post.



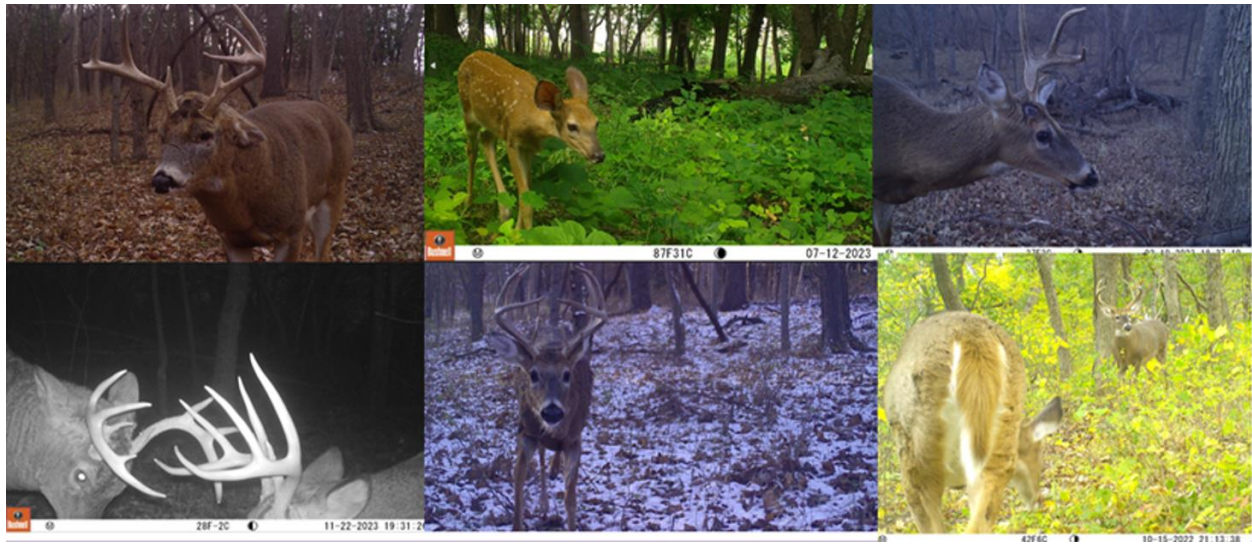
Appendix Figure B.3. Camera near highly palatable wild raspberries in a burn and thin area.



Appendix Figure B.4. Deer rub on a small tree in a burn and thin area.



Appendix Figure B.5. Deer browse on the lower leaves of a chinkapin oak sapling.



Appendix Figure B.6. Deer photos from Howe Natural Resource Education Center.



Appendix Figure B.7. First time gathering cameras data in July 2022.