AVIAN CONSERVATION & ECOLOGY

**VOLUME 19, ISSUE 1, ARTICLE 1**

Roy, C. L., J. Giudice, and L. M. Shartell. 2024. Sharp-tailed Grouse increase site use after prescribed fire but not mechanical treatments during the fall. Avian Conservation and Ecology 19(1):1. https://doi.org/10.5751/ACE-02574-190101

*Research Paper*

# Sharp-tailed Grouse increase site use after prescribed fire but not mechanical treatments during the fall

*Charlotte L. Roy*[1], *John Giudice*[2] *and Lindsey M. Shartell*[3]

[1]Wildlife Populations and Research Group, Minnesota Department of Natural Resources, [2]Wildlife Biometrics Unit, Minnesota Department of Natural Resources, [3]Division of Fish and Wildlife, Minnesota Department of Natural Resources

ABSTRACT. In the Great Lakes Region, Sharp-tailed Grouse (*Tympanuchus phasianellus*) use open habitats of grass and brush that require frequent management. Wildlife managers expressed concern that Sharp-tailed Grouse were not responding to management throughout the year, so we examined responses to prescribed fire and mechanical treatment (mowing or shearing) conducted during the fall. We surveyed Sharp-tailed Grouse use and vegetation at 15 mechanical treatments, 10 prescribed burns, and 25 control sites in a before-after-control-impact-paired design. We surveyed Sharp-tailed Grouse use before management, and one week, one month, one year, and three years after management by conducting fecal pellet surveys along transects at each site. Sharp-tailed Grouse responses, as indicated by differences between fecal pellet counts at treatments and paired controls during each survey, increased following prescribed fire, but did not change after mechanical treatments. However, increased Sharp-tailed Grouse use following prescribed fire was temporary, thus management should be conducted at least once every three years at each site. Changes in vegetation metrics at managed sites were also temporary and most metrics returned to pre-treatment levels after one year, although shrub height at sites that received mechanical treatments and the forb response following prescribed fire persisted for > 3 years. We suggest that fall prescribed fire is more effective at increasing Sharp-tailed Grouse use of sites than fall mechanical treatment, which could be due to differences in vegetation responses, site size, landscape context, or cues produced by fire that attract Sharp-tailed Grouse. However, mechanical treatments maintain Sharp-tailed Grouse habitat, and without management, unchecked woody encroachment reduces habitat. Targeting mowing and shearing at sites known to be used by Sharp-tailed Grouse may prioritize management activities to sites that will have the most impact. Prescribed fire and mechanical treatments produced different Sharp-tailed Grouse and vegetation responses in the fall and should be used to address different management objectives.

## Hausse de l’utilisation par le Tétras à queue fine de sites ayant subi un brûlage dirigé, mais pas de sites ayant été traités mécaniquement à l’automne

RÉSUMÉ. Dans la région des Grands Lacs, le Tétras à queue fine (*Tympanuchus phasianellus*) utilise des milieux ouverts constitués d’herbes et de broussailles qui nécessitent des mesures fréquentes de gestion. Les gestionnaires de la faune sont préoccupés du fait que le Tétras à queue fine ne réagit pas aux mesures de gestion tout au long de l’année. Nous avons donc examiné les réactions de cette espèce suite à des brûlages dirigés et des traitements mécaniques (fauchage ou cisaillage) effectués à l’automne. Nous avons relevé la présence du Tétras à queue fine et la végétation sur 15 sites traités mécaniquement, 10 sites ayant fait l’objet d’un brûlage dirigé et 25 sites de contrôle, au moyen de l’approche BACI (before-after control-impact) avec appariement. Nous avons vérifié la présence de tétras avant la mesure de gestion, puis une semaine, un mois, un an et trois ans après la mesure, en effectuant des relevés de fèces le long de transects à chaque site. L’utilisation des sites par les tétras, telles que mesurées par la différence entre le nombre de fèces sur les sites traités et les sites de contrôle appariés lors de chaque relevé, a augmenté après les brûlages dirigés, mais n’a pas changé suivant les traitements mécaniques. Cependant, l’augmentation de l’utilisation des sites par les tétras après les brûlages dirigés a été temporaire, et la mesure de gestion devrait donc être effectuée au moins une fois tous les trois ans à chaque site. Les changements quant aux paramètres de la végétation aux sites aménagés étaient également temporaires et la plupart des paramètres sont revenus aux niveaux d’avant le traitement après un an, bien que la hauteur des arbustes aux sites ayant été traités mécaniquement et la réaction des plantes herbacées après le brûlage dirigé aient persisté pendant plus de 3 ans. Nous pensons que les brûlages dirigés d’automne sont plus efficaces pour augmenter l’utilisation des sites par les tétras que les traitements mécaniques à l’automne, ce qui pourrait s’expliquer par des différences dans la végétation, la taille du site, le contexte du paysage ou les indices produits par le feu qui attirent cette espèce. Toutefois, les traitements mécaniques maintiennent l’habitat du Tétras à queue fine, et sans mesure de gestion, l’empiètement non-contrôlé des plantes ligneuses le réduit. Le fait de cibler le fauchage et le cisaillage sur des sites connus pour être utilisés par le tétras peut permettre de prioriser les activités de gestion là où elles auront le plus d’effets. Les brûlages dirigés et les traitements mécaniques ont entrainé des réactions différentes du Tétras à queue fine et de la végétation à l’automne, et devraient donc être choisis en fonction des objectifs de gestion à atteindre.

Key Words: *brushland management; mowing; pellet surveys; Tympanuchus phasianellus; wildlife habitat*

**Corresponding author:** Charlotte L. Roy, charlotte.roy@state.mn.us

## INTRODUCTION

Sharp-tailed Grouse (*Tympanuchus phasianellus*) in the Great Lakes Region depend on large areas (2–8 km²) of early successional habitats consisting of open grass, brush, savanna, and boreal peatland created and maintained through disturbance (Grange 1948, Ammann 1957, Rippin and Boag 1974, Krobinger 1980, Prose 1987, Berg 1997, Niemuth and Boyce 2004). Historically, lightning ignited grassland fires during the growing season, and Native Americans set fires to aid hunting during both the spring and fall dormant seasons (Grange 1948, Higgins et al. 1987, see review in Knapp et al. 2009), with fire return intervals of 0–10 years. Native Americans referred to the Sharp-tailed Grouse as the "fire grouse" or "fire bird" because of their use of habitats kept open by fire. Today, wildlife managers maintain grass and brush in early successional states by causing periodic disturbance with tools such as prescribed fire. Safe and effective application of prescribed fire requires a narrow set of conditions to be met and considerable staff and resources. Thus, wildlife managers supplement prescribed fire with mowing of herbaceous vegetation and smaller diameter brush, as well as shearing of overmature brush.

Wildlife managers in Minnesota expressed concern that Sharp-tailed Grouse were not responding to habitat management (i.e., prescribed fire, mowing, shearing) conducted throughout the year. However, habitat limitations are thought to be the reason for declines in Sharp-tailed Grouse populations in Minnesota, coinciding with large-scale habitat losses since the 1950s (Berg 1997, Roy 2022). Wildfire suppression, loss of small farms, and habitat succession to dense brush and forests have contributed to large-scale landscape change in the last century and reduced Sharp-tailed Grouse populations (Berg 1997).

We identified several possible reasons that Sharp-tailed Grouse responses to management might be lower than expected. For area-sensitive species, like Sharp-tailed Grouse, large area requirements might influence the effectiveness of management efforts. Thus, the size of management treatments, and the size of habitat areas adjacent to management treatments, may be important in determining Sharp-tailed Grouse responses, with a possible threshold size beyond which grouse are more likely to respond. Managing areas that are too small for target species may result in no response (Crosby et al. 2013, Fulbright et al. 2018). Moreover, the landscape context constrains the success of local management activities, such that local management is unlikely to be successful unless occurring in a landscape where higher-order processes like land conversion and fragmentation through woody encroachment are addressed (Fuhlendorf et al. 2017). Another possibility is that mechanical treatments are not producing the same cues for habitat creation that wildfire does (e.g., smoke, flames, dark burned ground). Such disturbance cues can be visible from a long distance and may attract grouse to recently disturbed areas. Numerous bird species are known to be attracted to fire, smoke, and recently burned areas (Higgins et al. 1987, Brown and Smith 2000). Because mechanical treatments do not replicate these cues, we might expect wildlife responses to management lacking these cues to be delayed or muted. Other wildlife species have been documented to respond differently to fire and mechanical treatments. In Florida shrub-grassland, birds in the community colonized burned plots earlier than mechanically treated plots, in which shrubs were roller chopped to knock down vegetation and crush the stems (Fitzgerald and Tanner 1992); birds were observed in burned plots the day after the fire but did not appear for months in roller-chopped plots. Moreover, numerous species responded differently to burned and roller-chopped plots over prolonged periods; throughout the 15-month study, species richness and abundance were lower in winter chop plots than in burned and control plots. Fitzgerald and Tanner (1992) suggested this was because burned plots provided more complex structure than mechanically treated plots, which leads to a third possible reason for muted responses to management; removal of vegetation structure in mechanical treatments may temporarily reduce the attractiveness of early successional habitats to some wildlife. This may produce time lags in use of habitats after mechanical treatments by target species, which may be important to understand.

A few studies have examined Sharp-tailed Grouse responses to spring prescribed fire (Kirsch and Kruse 1973, Sexton and Gillespie 1979), but we are unaware of any studies that have examined Sharp-tailed Grouse responses to prescribed fire or any type of management in the fall. However, fall may be a particularly important season to study responses to management because Sharp-tailed Grouse hens can respond (e.g., move to an area) more immediately to management than they might be able to in other seasons when they are tied to nest sites or constrained by broods. Juvenile Sharp-tailed Grouse are also dispersing during September and October (Gratson 1988) and may be exploring new areas at this time. In the fall, Sharp-tailed Grouse also dance at leks; Hamerstrom and Hamerstrom (1951) suggested that these fall dances, which include young males, might establish leks for the following spring. Importantly, sites burned in the fall are not followed by regrowth of vegetation during winter (Higgins et al. 1987, Kruse and Higgins 1990) and could serve as lek sites the following spring. This study aimed to measure the response of Sharp-tailed Grouse to prescribed burning and mechanical treatments in the fall, relative to untreated controls.

We measured Sharp-tailed Grouse responses to management using fecal pellet counts to assess site use. Pellet counts have been used to estimate grouse densities and grouse responses to management in other studies (Savory 1978, Dahlgren et al. 2006, Evans et al. 2007, Hanser et al. 2011, Schroeder and Vander Haegen 2014). Pellet counts have been shown to be indicative of the relative abundance of Greater Sage-grouse (*Centrocercus urophasianus*; Hanser et al. 2011), density of Red Grouse (*Lagopus lagopus scoticus*; Evans et al. 2007), and habitat use of Red Grouse (Savory 1978). Greater Sage-grouse responses to mechanical and chemical treatments have been compared with pellet counts along transects in plots (Dahlgren et al. 2006), as well as Greater Sage-grouse responses to wind farms using circular transects (Schroeder and Vander Haegen 2014). Pellet count effectiveness and relative ease of use, as well as the direct link to site use that is not available with some other methods (e.g., radio-marked birds may not use sites after marking), contributed to our selection of this method to compare Sharp-tailed Grouse responses to management.

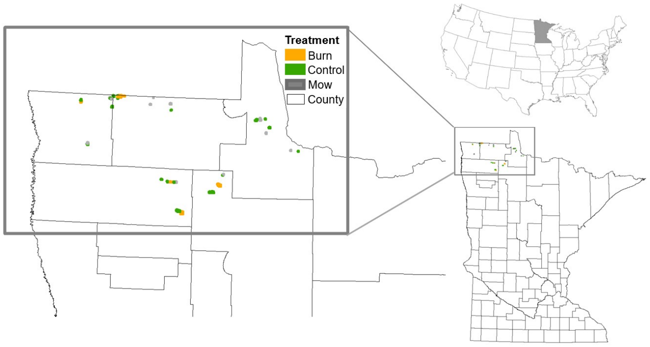
Our objectives were: (1) to compare Sharp-tailed Grouse use and vegetation metrics between control sites and sites managed with prescribed fire or mechanical treatments both before and after management during the fall, and (2) to compare vegetation metrics between sites where Sharp-tailed Grouse use was detected and sites where use was not detected. We hypothesized that Sharp-tailed Grouse use would increase following management, with use of burned sites increasing more than mechanically treated sites, and both treatments having more use than controls. We also hypothesized that vegetation metrics would differ between sites where Sharp-tailed Grouse use was detected and sites where use was not detected. We expected that sites not used by Sharp-tailed Grouse would have a greater proportion of shrub cover and taller shrub height as shrubs become overdominant without management.

# METHODS

## Study Area

Our study was conducted at grassland and brushland sites of the five most northwestern counties in Minnesota, USA (Fig. 1). This area includes portions of the Prairie Parkland Province, the Tallgrass Aspen Parklands Province, and the Laurentian Mixed Forest Province of Minnesota. During the study, the falls of 2018 and 2021 were dry, whereas 2016, 2019, and 2020 were wet (Palmer Drought Severity Index from Minnesota climate trends https://arcgis.dnr.state.mn.us/ewr/climatetrends/) and minimum winter temperatures were warmer than historical values.

**Fig. 1.** Sites that received mechanical treatments (mowing/shearing) or were treated with prescribed fire, and control sites for this study in which Sharp-tailed Grouse (*Tympanuchus phasianellus*) use and vegetation metrics were measured during 2015-2021 in northwestern Minnesota.



We asked wildlife managers to select sites to be managed for Sharp-tailed Grouse and to help identify suitable control sites located near treatment sites that had similar size and vegetative composition to treated sites. Treated study sites were mainly on state-managed lands, however three sites owned and managed by The Nature Conservancy (TNC) and three privately owned sites were included. Sites selected as treatments and controls averaged ~1 km from known leks in the annual survey area, but 13 sites were located outside the annual survey area and nearest lek locations were not known.

## Field data collection

We examined 28 management sites for Sharp-tailed Grouse responses to prescribed fire and mechanical treatment (mowing and shearing, hereafter, mowing) in the fall from 2015–2021 (Table 1; range: 2.0–268.7 ha). Management goals focused on maintaining existing brushland or sedge/grass communities by reducing shrub canopy and height, top-killing brush, reducing fine fuels, and keeping aspen in an early successional state. Prescribed burns were conducted with water units including type seven engines, tracked ATVs, UTVs, Argos, and/or tractors, and handheld drip torches and/or ATV-mounted torches. Conditions expected to result in a safe and effective fire varied among sites but were between 35–85° F, 18–60% relative humidity, and with winds of 4–20 mph. Parameters outside these bounds were considered "out of prescription." Mowing was conducted with skid steers with rotary mowers, sometimes with a fecon head for mulching. Mowed vegetation was cut to meet site goals (e.g., 0.15–0.41 m remaining height). Treatment dates reflected the dates of management activities (Table 1).

**Table 1.** Management treatment and size of sites managed for Sharp-tailed Grouse (*Tympanuchus phasianellus*) habitat in northwestern Minnesota during fall 2015–2018 and associated control sites, in order of treatment date. Most managed sites were on Wildlife Management Areas (WMA) with a few exceptions.

| Site | Treatment | Treatment date | Treatment (ha) | Control (ha) |
|---|---|---|---|---|
| Roseau River WMA 2015 | Mow | 28 Aug–16 Sep 2015 | 12.5 | 11.3 |
| Skull Lake WMA | Burn | 1 Sep 2015 | 36.4 | 28.3 |
| Halma WMA 2015 | Mow | 16–23 Sep 2015 | 16.6 | 15.8 |
| Red Lake WMA Mow | Mow | 22 Sep 2015 | 4.9 | 8.9 |
| Spooner WMA | Mow | 28 Sep 2015 | 8.9 | 10.5 |
| Caribou WMA[†] | Burn | 28 Sep 2015 | 268.7 | No control |
| Thief Lake WMA Burn | Burn | 28 Sep 2015 | 23.5 | 12.5 |
| Red Lake WMA Burn | Burn | 19 Oct 2015 | 61.5 | 71.2 |
| Prosper WMA 2015 | Mow | 19–30 Oct 2015 | 25.5 | 81.3 |
| Thief Lake WMA Mow | Mow | 30 Oct 2015 | 8.1 | 7.7 |
| Thief Lake 2016 | Burn | 1 Sep 2016 | 12.5 | 15.0 |
| Noracre | Burn | 14 Sep 2016 | 28.7 | 8.9 |
| Roseau River WMA 2016 | Mow | 27 Sep–7 Oct 2016 | 9.3 | 11.7 |
| Espelie WMA | Burn | 3 Oct 2016 | 179.3 | 186.2 |
| Halma WMA 2017 | Mow | 28 Aug–8 Sep 2017 | 25.0 | 25.0 |
| Gates 2017 | Burn | 8 Sep 2017 | 157.0 | 129.0 |
| K 2017 | Burn | 13 Sep 2017 | 36.0 | 38.0 |
| F 2017 | Burn | 13 Sep 2017 | 40.0 | Same as K |
| Prosper WMA 2017 | Mow | 27 Sep–26 Oct 2017 | 28.0 | 17.0 |
| O 2017[†] | Burn | 9 Oct 2017 | 7.0 | 40.0 |
| I 2017[†] | Burn | 9 Oct 2017 | 19 | Same as O |
| Thief Lake WMA 3 | Mow | 21 Sep–10 Oct 2018 | 29.5 | No control |
| Graceton WMA | Mow | 1–11 Oct 2018 | 30.4 | 36.0 |
| Roseau River HQ | Mow | 4–5 Oct 2018 | 2.0 | 2.5 |
| Thief Lake WMA 2018 | Mow | 24 Sep–16 Oct 2018 | 21.4 | 18.2 |
| TNC site 10 | Mow | 19–22 Oct 2018 | 4.5 | Same as site 9 |
| Roseau River WMA 2018 | Mow | 17–25 Oct 2018 | 3.6 | Same as HQ |
| TNC site 9 | Mow | 23–27 Oct 2018 | 18.2 | 17.4 |

[†] These sites were excluded from the matched-pair analysis because they lacked controls or their control site was compromised by disturbance (e.g., grazing).

We surveyed sites to document Sharp-tailed Grouse use 0–28 (median 8.0) days before (PRE) management, and one week (1WK), one month (1MO), one year (1YR), and three years (3YR) after management at sites managed during 2015–2018. Management treatments were implemented between late-August and the end of October so that 1MO surveys could be conducted before the end of November, when snow can cover pellets temporarily. Less brushland management usually occurs during November because of overlap with deer hunting season and comparatively short burn windows relative to other times of year (J. Ekstein, MNDNR, *personal communication*).

We attempted to match sites receiving management treatments with a control site of similar size, vegetative composition, and successional stage based on crude visual assessment of the percent cover of shrubs, percent cover of herbaceous vegetation, and average shrub height. To do this, we visually inspected aerial imagery, had conversations with managers, and conducted site visits. We attempted to identify control sites ≤ 6 km from treatment sites, when possible, based on dispersal distances of young males in the fall (Gratson 1988), to control for variation in grouse densities in local areas that might influence the number of grouse in the area that could respond to management. Control sites also helped account for changes in site use related to seasonal progression including seasonal changes in habitat use, social behavior, and weather that were unrelated to management. A similar design was implemented by Dahlgren et al. (2006) to account for temporal differences in the application of management treatments for Greater Sage-grouse.

We surveyed treatment and control sites within 21 days of each other, both before and after treatment (Smith 2002, also see Morrison et al. 2001a), to minimize confounding related to seasonal progression. Usually, sites planned for management were surveyed before control sites due to the urgency of completing pre-treatment surveys ahead of management activities for which notification of management timelines were short, whereas at control sites, delay of a day or more would not preclude collection of data at the site and inclusion in the study.

We assessed Sharp-tailed Grouse site use by surveying for fecal pellets along transects. Transects were systematically spaced ≥ 150 m apart, with a starting point placed on the site boundary and traversing the site to capture both edge and interior portions of the site. We standardized the sampling rate to 25 m/ha based on placement of pellet transects in other studies (Evans et al. 2007, but half as dense as Dahlgren et al. 2006, Hanser et al. 2011). We counted Sharp-tailed Grouse pellet piles ≤ 0.5 m from the pellet transect and removed all pellets encountered (Evans et al. 2007, Schroeder and Vander Haegen 2014). Pellets were classified as either single or grouped pellets (roost piles, excluding caecal droppings), and our primary monitoring metric was the total number of pellet groups (single pellets + roost piles) detected at each site and visit. Thus, roost piles and single pellets were both counted as one observation. When vegetation was dense, we used a hockey stick to move the vegetation slightly to improve visibility of the ground below. We also recorded any Sharp-tailed Grouse observed at the site and the distance and direction of grouse from the pellet survey transect. Other signs of grouse use were also documented including tracks and feathers, as ancillary data to supplement our pellet transect data.

We anticipated that differences in mean pellet counts between treatments and time-since-treatment could partly reflect changes in the observation process. For example, we reasoned that removing vegetation via fall mowing or burning might increase the detectability of pellets, but the effect would probably be short-lived (< 1 year) due to vegetation regrowth. To better understand the detection process, we conducted experimental pellet-transect surveys (hereafter, pellet-detection transects), where we placed pellets (collected during other field activities) ≤ 1 m from a 100-m tape in different vegetation types (i.e., shrubs, grass, grass-shrub, burned ground, etc.), treatments (mowed, burned, untreated), and time-since-treatment periods (PRE, 1MO, 1YR). Field technicians then surveyed the pellet-detection transects and recorded locations of detected pellets (not caecal droppings), vegetation type at the pellet location, and pellet types (roost piles or single pellets, where roost piles consisted of groups of pellets). We quantified detection of single pellets separately from roost piles (simulated with 4-5 pellets) because we predicted that detectability would be higher for roost piles. These pellet-detection transects enabled quantification of pellets that were missed and detected in different vegetation types, following treatment with prescribed fire and mowing at managed sites and control sites. Our goal was not to develop Horvitz-Thompson-type correction factor (e.g., Thompson 2002), but rather to better understand the pellet detection process and how it might influence our ability to make inferences about differences in site use over time and between treatments.

We sampled vegetation within treatment and control sites, before and after treatment, using point-intercept sampling (Levy and Madden 1933, Dahlgren et al. 2006). We determined percent cover and average height of vegetation in four vegetation classes defined for this study as follows; trees were perennial, woody plants with a single stem that will grow > 5 m; shrubs were perennial woody plants with multiple stems typically 1–5 m when fully grown; forbs were vascular herbaceous plants including ferns, vines, and woody plants < 1 m tall when fully grown; and graminoids were grass or grass-like plants including sedges and rushes. We sampled vegetation along 20-m transects placed perpendicular to and spaced evenly along the pellet survey transect, with the number of vegetation transects per site determined by site size. Five, 10, 15, and 20 vegetation transects were surveyed for sites < 12 ha, 12–81 ha, 81–202 ha, and > 202 ha, respectively. We marked the start of each vegetation transect with ground staples, numbered aluminum tags, and flagging, and recorded GPS coordinates to relocate transects for subsequent surveys. We used a pole with graduated measurements every 0.1 m to determine the highest point at which vegetation from each class touched the pole, which was similar to a Robel pole (Robel et al. 1970) but taller to allow for measurement of tall shrubs and trees. We recorded maximum height for each vegetation class every 1.0 m along the transect for a total of 20 points per transect.

## Analysis

We conducted all analyses in the R Programming Language (R Core Team 2022; R version 4.3.1). Because we used a before-after-control-impact paired (BACIP) design with matched treatment and control sites (e.g., Morrison et al. 2001a) to examine Sharp-tailed Grouse responses to management, our response metric was the difference in pellet counts (site- and time-specific totals adjusted for transect length and expressed as pellets/km) between paired treatment and control sites for each survey period (PRE, 1WK, 1 MO, 1YR, 3YR; Table 2), which approximated a normal distribution. We used the lmer function in the lme4 package (Bates et al. 2015) to fit a linear mixed-effect model with treatment (mow vs burn), time, and treatment:time as fixed effects and site as a random intercept term to account for repeated surveys. We computed and compared population-level means with the emmeans package (Lenth 2022).

To analyze the pellet-detection transect data, we used the glmer function in the lme4 package (Bates et al. 2015) to fit a mixed-effect logistic model. Fixed effects included treatment:time groups (untreated, burned one month ago, burned one year ago, mowed

**Table 2.** Sample sizes (matched pairs of treatment and control sites, except for the Sum column, which is total surveys) for the matched-pairs analysis of Sharp-tailed Grouse (*Tympanuchus phasianellus*) pellet surveys in northwestern Minnesota during 2015–2021 before management (PRE) and after management at 1 week (1WK), 1 month (1MO), 1 year (1YR), and 3 years (3YR) post-treatment.

| Treatment | PRE | 1WK | 1MO | 1YR | 3YR | Sum |
|---|---|---|---|---|---|---|
| Mow | 15 | 12 | 8 | 14 | 8 | 57 |
| Burn | 9 | 8 | 7 | 7 | 4 | 35 |
| Sum | 24 | 20 | 15 | 21 | 12 | 92 |

one month ago, mowed one year ago) and pellet type (single pellet vs roost). Random effects included random intercept terms for transect and observer. We used the emmeans package (Lenth 2022) to compute population-level means (based on fixed effects only) and 85% confidence intervals and compared relative differences graphically using a barplot with error bars.

We analyzed each vegetation metric (excluding trees, which had 5% proportional coverage on our sites) separately using a mixed-effect linear model with fixed effects for treatment, time, and treatment:time, and a random intercept for site. We also dropped the matched-pair requirement for vegetation analyses because it was difficult to find nearby suitable controls for a few sites. This approach likely increased our comparison-wise error rate but allowed inclusion of sites that did not have a complete survey history or lacked matched controls, which increased our sample size (i.e., 12 burn, 15 mow, 21 control sites). Given the limitations of our analysis and dataset, we graphically compared marginal means and 85% confidence intervals across treatments and time. We used the lme4 package (Bates et al. 2015) to fit and evaluate each mixed model. We applied an arcsin transformation (Zar 1996) to proportional cover metrics prior to analysis, but back-transformed the marginal means for plotting. We computed marginal means using the emmeans package (Lenth 2022).

To examine the relationship between Sharp-tailed Grouse site use (detection, non-detection) and vegetation metrics on managed sites, we used the glmmTMB package to fit a logistic model (Brooks et al. 2017) with fixed effects for vegetation metrics (mean height and composition by survey period, excluding tree metrics) and a random intercept for site. We used the Anova function in the car package (Fox and Weisberg 2019) to assess individual vegetation effects and evaluated the combined effect of vegetation metrics (fixed effects) by comparing the full model to a null model with only an intercept and random-effect terms. For this analysis, we used detection/non-detection data that included both bird sightings and grouse signs observed both on and off formal pellet-survey transects.

To examine the landscape context in which study sites occurred, we used two approaches. First, we buffered each site with a 2 km buffer in ArcMap 10.6 (ESRI®, Redlands, CA, USA) and used the North American Land Change Monitoring System (NALCMS) layer to quantify shrubland, grassland, and wetland in these buffers with the Tabulate Area 2 Tool. In this way, we quantified the habitat ≤ 2 km of the sites, some of which occurred near the USA-Canada border necessitating use of the NALCMS. In a second approach, we quantified the amount of contiguous habitat in which the study sites occurred. To do this, we used 2016 National Land Cover Data, converted it from a raster to a polygon file, then aggregated emergent herbaceous wetlands, hay/pasture, herbaceous, and shrub-scrub land cover types separated by no more than 31 m from each other (grid cells were 30 m x 30 m) that contained the site. We then calculated the area of this aggregated polygon to obtain the contiguous area of habitat within which the site occurred. This approach did not constrain the habitat to be within a particular distance of the site, only that the habitat was separated by no more than 30 m from nearby habitat.

## RESULTS

### Site attributes

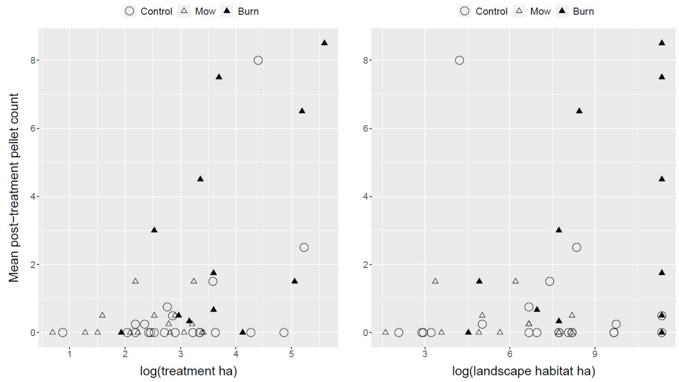
We conducted pre-treatment pellet and vegetation transect surveys at 54 sites planned for management and 39 control sites during mid-August through mid-October 2015–2018. However, wildlife managers were only able to execute 16 mowing treatments and 12 prescribed fire treatments (Table 1) because of weather, staffing, and equipment availability. Furthermore, two sites (one burn, one mow) lacked paired controls and two sites (both burns) had their control compromised (e.g., grazed) during the study (Table 1). Six sites (two burn, four mow) received multiple treatments before the 3YR survey. These data could not be interpreted as resulting from the study treatment. Finally, some surveys were compromised by snow or flooding that may have concealed pellets (e.g., snow in 3-1WK and 10-1MO surveys, 1 site flooded at 3YR) so data for some surveys were not comparable (PRE, 1WK, 1MO, 1YR, 3YR). Thus, sample sizes varied by response metric (e.g., pellet counts vs vegetation metrics) and survey period, and depended on assumptions of each analysis (e.g., matched-pairs analysis). However, based on the 28 sites listed in Table 1, along with their controls which were 4.02 ± 0.97 km from treatment sites, we can describe some general attributes of burned, mowed, and control sites in this study.

Burned sites tended to be larger (mean = 73 ha; median = 36 ha; range: 7–269 ha) than mowed sites (mean = 15 ha; median = 14 ha; range: 2–30 ha) or controls (mean = 36 ha; median = 17 ha; range: 2–186 ha). However, total m of pellet transects was size dependent and, thus, survey effort was similar for burned sites (mean = 27 m/ha; median = 28 m/ha; range: 4–55 m/ha), mowed sites (mean = 39 m/ha; median = 32 m/ha; range: 21–93 m/ha), and controls (mean = 34 m/ha; median = 30 m/ha; range: 14–111 m/ha). The amount of contiguous habitat in the surrounding landscape was, on average, much larger for burned sites (mean = 438 km²; median = 435 km²; range: 1–860 km²) than mowed sites (mean = 170 km²; median = 8 km²; range: 0–860 km²) or controls (mean = 116 km²; median = 23 km²; range: 0–860 km²). Conversely, the relative amount of habitat within a 2-km buffer was similar for burned sites (mean = 61%; median = 56%; range: 36–98%) and mowed sites (mean = 56%; median = 54%; range: 21–98%), and slightly higher for control sites (mean = 61%; median = 63%; range: 18–100%). Likewise, prior to management treatments, study sites had similar vegetative attributes with most sites dominated by graminoid cover (mean = 96% coverage; range: 58–100%) and moderate coverage of forbs (mean = 32%; range: 0–96%) and shrubs (mean = 34%; range: 1–83%). Tree coverage was very low on most sites (mean = 5%; range: 0–37%). The pre-treatment vertical structure (sample distributions of mean vegetation height) was similar among burn and mow sites, whereas some control sites contained taller shrub and trees (i.e., in the right tail of the sample distributions).

## Pellet surveys: summary statistics

Observers conducted 206 pellet surveys, although only 56 surveys (27%) resulted in pellet detections. The overall conditional pellet count (given ≥ 1 pellet detected) averaged 3.6 pellet groups (median = 1.5; range: 1–32), with 52% of the detections being single pellets. However, when all surveys were combined, 25 sites (51%, including controls) had at least 1 survey in which ≥ 1 pellet was detected and naïve use was highest for burned sites (83%) compared to mowed sites (50%) and controls (33%). An additional 11 sites (3 burn, 5 mow, 3 controls) had ancillary detections of birds or bird signs. However, at the individual survey scale, formal pellet surveys (detection, non-detection) and ancillary detection data had high concordance (0.94). Mean post-treatment pellet counts (site-level counts averaged over post-treatment visits) at managed sites were positively associated (rho = 0.70; 95% CI: 0.45 to 0.85) with treatment size but only weakly associated (rho = 0.37; 95% CI: 0 to 0.66) with log(contiguous habitat). Conversely, mean pellet density (pellets per km of transect surveyed) at managed sites was not strongly correlated with treatment size (rho = 0.08; 95% CI: -0.30 to 0.44) or contiguous habitat (rho = 0.23; 95% CI: -0.15 to 0.56). The main design issue is that treatment size and the amount of contiguous habitat were both confounded with treatment type (i.e., burned sites tended to be larger and have greater contiguous habitat; Fig. 2). Furthermore, these relationships were strongly influenced by two large burn sites that also had large amounts of contiguous habitat (Fig. 2).

**Fig. 2.** Scatterplots of mean post-treatment pellet counts (site-level counts averaged over post-treatment visits) at managed and control sites versus treatment size and amount of contiguous habitat around study sites.



## Pellet surveys: matched-pairs analysis

We excluded four treatment sites (three burn, one mow) from the matched-pairs analysis because they lacked controls or the control site was compromised (e.g., grazed) during the study. We also had three treatment sites (one burn, two mow) that received multiple treatments during the study; in these cases, we only used survey data collected prior to the second management treatment. Our final dataset for the matched-pairs analysis contained 15 sites that were mowed and 9 sites treated with prescribed fire, along with their paired controls. The number of treatment sites surveyed over time ranged from 24 (15 mow, 9 burn) in PRE to 12 (8 mow, 4 burn) in 3YR (Table 2).

In the analysis of the difference in pellets/km between matched pairs of treatment and control sites at each time-since-treatment period, the mean difference (treatment-control) did not differ as a function of treatment:time (Chisq = 2.86, df = 4, P = 0.581), which is the key hypothesis test of interest in a BACI design (Morrison et al. 2001a). The lack of a significant interaction term indicated the treatment effect was not sustained or was not sufficient to alter the mean response on treated sites over all sampling times. However, pairwise contrasts of mowing vs prescribed fire treatments at each survey period indicated that, compared to their matched controls, burned sites tended to have more pellet groups (per km) than mowed sites at 1YR post-treatment (Fig. 3). Population-level mean differences (treatment-control) were positive and highest for sites treated with prescribed fire, whereas mowed sites had similar pellet counts to their matched controls (Fig. 3).

## Pellet detectability

Twelve observers conducted 126 pellet-detection surveys at 90 transects on 25 sites (7 burn, 7 mow, 11 untreated) during September–November 2015–2019. Pellet density averaged 21 pellet groups/100 m (range: 6–67) and single pellets comprised an average of 52% of available pellet groups (range: 17–76%). Approximately 35% of surveys were conducted on sites treated with prescribed fire, 38% on mowed sites, and 27% on untreated sites with a diversity of dominant vegetation types (e.g., grass, tall grass, grass-forb, grass-forb-shrub, grass-forb-shrub-trees, grass-shrub, grass-shrub-trees, and shrubs). Treatment groups for this analysis consisted of untreated, one-month and one-year post-mowing, and one-month and one-year post-prescribed fire treatment, with a reasonably balanced distribution of surveys/group (relative distribution: 16–27%). Vegetation did not grow back the month after management due to senescence of vegetation; consequently, we assumed pellet detection was similar in 1WK and 1MO pellet surveys.

**Fig. 3.** Mean predicted difference in Sharp-tailed Grouse (*Tympanuchus phasianellus*) pellet counts/km between treatment and controls in five surveys: pre-management (PRE), one week (1WK), one month (1MO), one year (1YR), and three years (3YR), for sites treated with mowing/shearing vs prescribed burns in northwestern Minnesota during 2015–2021 based on a before-after-control-impact paired study design and a mixed-effect linear model.

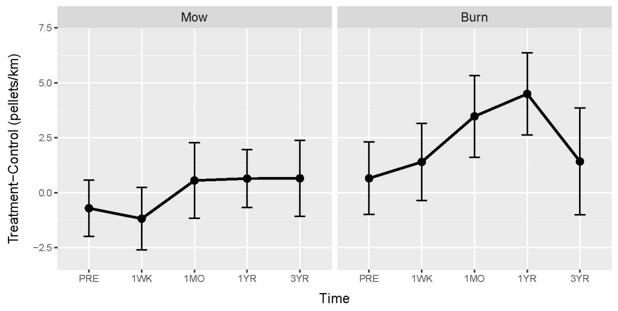


**Fig. 4.** Mean predicted detection probabilities for Sharp-tailed Grouse (*Tympanuchus phasianellus*) pellet groups on untreated, mowed, and burned transects. Predicted probabilities are marginal means from a mixed-effect logistic regression model that contained fixed effects for treatment group and pellet type, and random intercept terms for transect and observer ID. Error bars denote 85% confidence intervals.

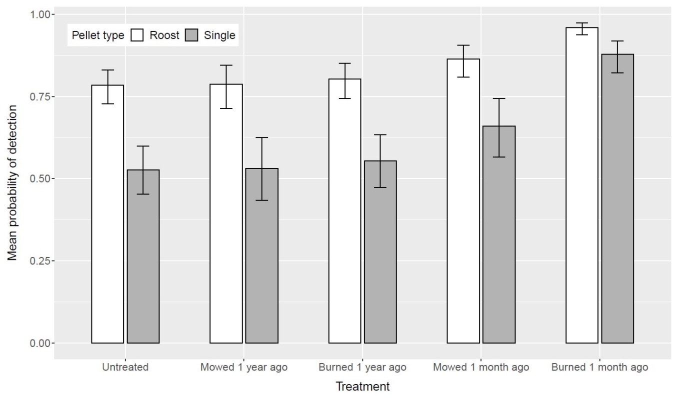
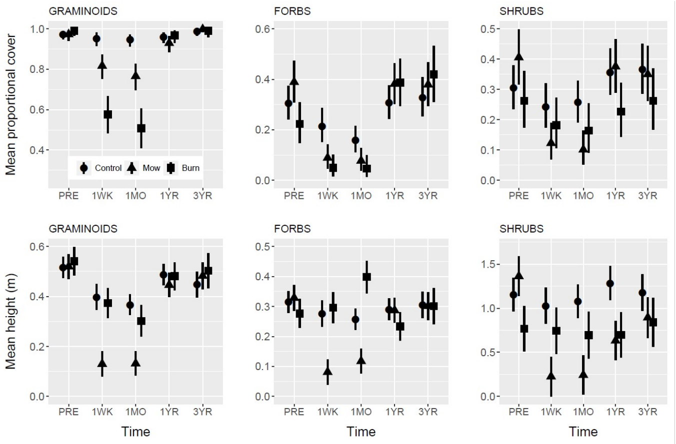


**Fig. 5.** Marginal means and 85% confidence intervals (CIs) from mixed-effect linear models fit to each vegetation metric (separately), where each model contained fixed effects for treatment, time, and treatment:time, and a random intercept for site.



Overall, observers detected 72% of pellet groups available during pellet detection transect surveys. However, based on our logistic-analysis model, the mean detection probability varied by treatment group and pellet type, with the lowest probability (0.53; 85% CI: 0.45 to 0.60) associated with single pellets on untreated sites and the highest probability (0.96; 85% CI: 0.94 to 0.97) associated with roost piles on sites burned one month ago (Fig. 4). This is consistent with predicted differences due to vegetation removal, especially for burned sites, and pellet type, with roost piles having a higher mean detection probability. In both prescribed fire and mowing treatments, the mean detection probability returned to untreated levels within one year after management (Fig. 4).

## Vegetation surveys

Our analysis dataset contained 27 treatment sites (15 mow, 12 burn) and 21 control sites, but the number of sites surveyed over time ranged from 48 (15 mow, 12 burn, 21 controls) in PRE to 32 (7 burn, 12 mow, 13 controls) in 3YR, due in part to repeated disturbance before the 3YR survey. The mean proportional cover of forbs, graminoids, and shrubs decreased at mowed sites in 1WK and 1MO surveys, but these effects disappeared within 1YR (Fig. 5). Mean height of forbs, graminoids, and shrubs were lower on mowed sites compared to both control and burned sites at 1WK and 1MO surveys, but forbs and graminoids returned to pre-treatment levels within 1YR of management, and shrubs followed a similar pattern with relatively small differences (< 1 m) at 1YR post-treatment. However, prior to any treatment, mowed sites tended to have taller shrubs than burned sites (Fig. 5), which may reflect different management histories for manager-selected mowed and burned sites. In contrast, at sites treated with prescribed fire, shrub height was largely unchanged with treatment, whereas mean forb height was higher at 1MO likely due to greater fire effects on senescing shorter forbs, whereas graminoids were temporarily reduced in height before returning to pre-treatment levels within 1YR. At sites treated with prescribed fire, proportional cover of graminoids and forbs was reduced at 1WK and 1MO, with more forb cover at 1YR and 3YR than PRE treatment and no change in shrub cover at any survey period.

We did not find an association between naïve occupancy (detection/non-detection, based on all grouse sign and/or sightings) and vegetation metrics during the five survey periods at study sites managed for Sharp-tailed Grouse (ANOVA table for full vs null model: Chisq = 4.10, df = 7, P = 0.768). Mean vegetation metrics were similar at managed sites where Sharp-tailed Grouse or their signs were detected and not detected (Table 3).

# DISCUSSION

## Sharp-tailed Grouse responses to management

Sharp-tailed Grouse use of study sites treated with prescribed fire increased immediately after management and this increased use lasted more than one year. In contrast, we did not find evidence of higher Sharp-tailed Grouse use of sites following mechanical treatment. Importantly, the removal of vegetation with management also increased the detectability of pellets immediately after management, and detectability increased more at burned sites, where pellets contrasted strongly against the dark, burned ground. However, pellet counts/km continued to increase between the 1WK and 1MO post-treatment surveys at sites treated with prescribed fire, despite similar detectability during this time when vegetation was senescent. Furthermore, pellet detectability returned to pre-treatment levels for the 1YR survey, yet site use remained elevated 1YR after management at sites treated with prescribed fire, indicating that higher Sharp-tailed Grouse use after treatment could not be entirely explained by changes in detectability. Thus, we are confident that Sharp-tailed Grouse use increased following treatment with prescribed fire, although estimating the magnitude of the response remains elusive due to changes in the detection process and the difficulty of translating pellet counts to absolute bird abundance.

**Table 3.** Mean vegetation metrics and 85% confidence intervals (in parentheses) at site-surveys where Sharp-tailed Grouse (STGR; *Tympanuchus phasianellus*) or their sign was detected or not detected during five sampling surveys in northwestern Minnesota during 2015–2021.

| Vegetation metric | STGR Detected | STGR Not detected |
|---|---|---|
| Mean proportion cover graminoid | 0.77 (0.72–0.83) | 0.87 (0.83–0.91) |
| Mean proportion cover forb | 0.24 (0.19–0.29) | 0.30 (0.26–0.35) |
| Mean proportion cover shrub | 0.27 (0.23–0.31) | 0.28 (0.24–0.33) |
| Mean height graminoid | 0.40 (0.36–0.44) | 0.40 (0.36–0.44) |
| Mean height forb | 0.24 (0.22–0.28) | 0.26 (0.24–0.29) |
| Mean height shrub | 0.72 (0.62–0.86) | 0.75 (0.65–0.84) |
| Tree presence/absence | 0.39 (0.28–0.50) | 0.35 (0.25–0.45) |

Initial site conditions at sites that managers selected for mowing/shearing treatments did differ from those selected for prescribed fire treatments. Sites selected for mechanical treatments were generally smaller, with the four sites > 50 ha all treated with prescribed fire. Management at smaller sites might be less noticeable to Sharp-tailed Grouse from a distance or may have less impact on available habitat. Sites receiving mechanical treatments also tended to have taller shrubs (median = 1.1 vs 0.8 m; max = 2.5 vs 1.1 m) before treatment, which likely reflected more advanced stages of woody encroachment, at least on some mow sites. These initial site differences might affect Sharp-tailed Grouse response to management. However, mechanical treatment more strongly affected vegetation height than prescribed fire, and that might also explain the lack of Sharp-tailed Grouse response because grouse use areas with herbaceous and shrub cover in the fall.

Graminoid, shrub, and forb height was markedly reduced immediately following mechanical treatment, but at sites managed with prescribed fire, only graminoid height was reduced with forb and shrub height largely unaffected. Mean forb height was higher at 1MO post-fire, perhaps due to greater fire effects on senescing low forbs than taller forbs in the fall. At sites treated with prescribed fire, the proportion of forb and graminoid cover was reduced immediately after management, but the proportion of shrub cover was unaffected, leaving vegetation height and structure more intact after prescribed fire than at sites receiving mechanical treatments. The strong reduction in vegetation height after mechanical treatments may influence Sharp-tailed Grouse responses (or lack of responses) immediately after management, as it does in other bird species (Fitzgerald and Tanner 1992). However, the impact of prescribed fire and mechanical treatments on the vegetation metrics we measured were temporary, with most vegetation metrics returning to pre-treatment levels within 1YR. Mechanical treatments reduced the proportion of shrub cover for less than one year, whereas shrub height returned to pre-treatment levels more slowly. Importantly, the primary shrubs in our study were alders (*Alnus* spp.) and willows (*Salix* spp.), which re-sprout, especially when management occurs during the dormant season and plant resources are below ground (Knosalla 2019).

We did not detect differences in vegetation metrics at managed sites where Sharp-tailed Grouse were detected compared to those where they were not detected. We suggest that most or all our study sites included Sharp-tailed Grouse habitat, which is why managers selected them for Sharp-tailed Grouse habitat management. Sharp-tailed Grouse use a variety of vegetation cover and heights to meet needs in the fall (e.g., shade, food, etc.). Our inability to detect differences in vegetation metrics between sites with and without grouse detections may also have resulted from: (1) imperfect detection of Sharp-tailed Grouse site use; (2) high variability in vegetation metrics within and among sites, which can make statistical differences harder to resolve; or (3) selected vegetation metrics may not have been sufficient to determine use by Sharp-tailed Grouse and other unmeasured factors may be important. Site use is also likely influenced by grouse densities in the area (e.g., nearby leks) and conspecific attraction (Campomizzi et al. 2008).

Importantly, the landscape context within which management occurs can be an important determinant of wildlife responses, particularly for area-sensitive prairie grouse which require large, intact landscapes of suitable habitat (Fuhlendorf et al. 2017). Management of sites within highly fragmented landscapes may have little impact on habitat availability if the minimum amount of habitat needed to support Sharp-tailed Grouse is not met, also called the habitat threshold (Fuhlendorf et al. 2017). The landscape context in which mowing/shearing treatments occurred was substantially different from those in which prescribed fire was implemented as a management tool. Mowing and shearing treatments were not applied to large sites, and these comparatively smaller sites occurred within less contiguous landscapes. Thus, we cannot separate the management treatment from the landscape context in which it occurred. However, a more prescriptive experimental approach may not have been sufficient to remedy this confounding factor in our study area. The biases in the application of management chosen by managers likely reflected the practicalities of applying management in these landscapes. Prescribed fire is more easily implemented safely, without smoke management concerns, in more intact landscapes, which in our study area had more public land, less traffic volume, and fewer residences. In more fragmented landscapes, mowing and shearing may be a more feasible management option for managers. However, mowing and shearing treatments are more costly than prescribed fire on a per hectare basis and may be cost-prohibitive at very large sites. The landscape differences between treatment sites in our study also may have influenced the numbers of Sharp-tailed Grouse available to respond to management, and thus, responses to mowing and shearing may have been muted somewhat due to potentially lower population densities in less contiguous landscapes. However, precise population estimates surrounding management sites within this five-county study area were not available to examine this.

We suggest that increases in Sharp-tailed Grouse site use after fall prescribed fire may not have resulted from the immediate changes in cover (which were more pronounced at mowed/sheared sites), but by another aspect of burning, e.g., smoke, dark burned ground, possibly burned invertebrate food items. Young grouse disperse and explore new areas in the fall (Gratson 1988). Grouse might also be attracted to fire, smoke, and recently burned areas as some Falconiformes, Strigiformes, and Passeriformes are (Komarek 1969, Vogl 1973, Brown and Smith 2000). Sharp-tailed Grouse evolved with fire. Importantly, prescribed fire leaves some vegetation structure intact that provides cover for Sharp-tailed Grouse and other wildlife, whereas mowing immediately and profoundly reduces vegetation structure.

## Management to benefit Sharp-tailed Grouse

We suggest that fall prescribed fire is more effective than fall mowing/shearing for increasing Sharp-tailed Grouse site use and may have other important benefits. Conducting prescribed burns in the fall extends the burn season outside the more common spring prescribed fire season and can increase the opportunities to do prescribed fire treatments, which maintain disturbance-dependent systems. Fall burns also set succession back without causing incidental nest failures and may increase the proportion of forb cover, which provides food sources for grouse chicks (Connelly et al. 2020). However, conducting prescribed fire in the fall also has some challenges. For example, windows for conducting prescribed fire in the fall are typically shorter than in the spring, which can impose additional constraints on conducting fall burns. Importantly, in our study, most sites that were planned for management, but which did not get managed, were sites for which prescribed fire was planned. Wildlife managers face many obstacles to reaching prescribed fire goals, including inappropriate wind speeds, wind direction, humidity, fuel conditions, staffing availability, etc. Nevertheless, conducting prescribed fire in more seasons can increase the number of burns that get accomplished. Prescribed fire can also produce more varied effects on brushland vegetation when applied in different seasons (Knosalla 2019) and varying the season of fire can reduce pressure on species that are more vulnerable to fire in some seasons such as nesting seasons (Knapp et al. 2009).

Mowing and shearing can help maintain habitat, which without management will progress to advanced stages of woody encroachment. Mowing and shearing may be less effective than burning at increasing Sharp-tailed Grouse site use but can set back succession of brushlands to maintain suitability for Sharp-tailed Grouse. We recommend that fall mowing and shearing be used at sites with existing Sharp-tailed Grouse use. We cannot eliminate the possibility that modifying mowing and shearing to leave some residual vegetation cover (e.g., mowing strips) could produce a different Sharp-tailed Grouse response than we observed, but that would require additional research.

Maintaining Sharp-tailed Grouse habitat requires an ongoing commitment to frequent management at intervals of < 3 years. Transient effects of brush management are commonly documented with diminishing benefits to target species over time (Fulbright et al. 2018). Thus, follow-up treatments are necessary for the conservation of Sharp-tailed Grouse. Ideally, for Sharp-tailed Grouse, management should prevent woody encroachment from progressing to decadent brushland and forest. Our findings indicate that shrub height was nearly recovered three years after mowing but burning had little effect on shrub height or shrub cover. Once woody vegetation becomes established at a site, fall prescribed fire may not be very effective at slowing its advancement. Another Minnesota study showed that burning during the growing season (summer) can impact shrub re-sprouting but burns during the dormant seasons (spring and fall) when energy is below ground resulted in more resprouting (Knosalla 2019, see also Knapp et al. 2009). Alternating burning and mowing/shearing might be effective, and combinations of management treatments in rapid succession are also worthy of study. Burning, mowing, and shearing are all effective management tools and understanding how responses to these tools vary will be advantageous to managers in meeting their Sharp-tailed Grouse management goals.

## Other seasons and regions

Our findings are specific to Sharp-tailed Grouse responses to management during the fall season, and we caution that it may not be appropriate to apply our findings to other regions. In the Great Lakes Region, Sharp-tailed Grouse use brushland habitats, but elsewhere in their range, they rely more on grassland habitats and thus might respond differently to management at earlier stages of succession. Moreover, site use and bird densities may be misleading indicators of habitat quality, so measuring reproductive success and survival should also be considered when evaluating management impacts (Van Horne 1983, Morrison 2001b). Nevertheless, a literature review of fire in the Great Plains concluded that burned areas are attractive to Sharp-tailed Grouse and several other gamebirds (Higgins et al. 1987).

Our findings are also specific to the fall season. Responses to habitat management might vary with the time of year depending on the habitat requirements at that time of year. Sharp-tailed Grouse use a variety of habitats throughout the year: leks are comprised of short or absent vegetation; nesting cover is taller with grasses, shrubs, and forbs; and dense forb cover provides insects for chicks in the summer (Connelly et al. 2020). Furthermore, Sharp-tailed Grouse may face different constraints to movement and site use throughout their life cycle. For example, only six of our managed sites were on/adjacent to known leks (although many lek sites are not known), and Sharp-tailed Grouse usually use areas ≤ 2 km of lek sites (Connolly 2001, Connelly et al. 2020). Nevertheless, other studies have documented Sharp-tailed Grouse responses to prescribed fire in other seasons. For example, Sharp-tailed Grouse moved lek sites two days after a spring prescribed fire, abandoning the former dancing ground to move to a nearby burned site (Sexton and Gillespie 1979). Higher brood density has been reported at sites the year after a prescribed fire than at unburned sites (Kirsch and Kruse 1973). Considering the timing of management in the broader context of the life history of a species is important because what may be beneficial to a species in one season may be detrimental to the same species in other seasons (Fulbright et al. 2018). For example, spring prescribed fire can destroy nests but fall fires do not. Moreover, if nesting habitat is limiting, removing nesting habitat to create lek habitat will not be beneficial. All management decisions include trade-offs, in which some species will benefit and some species will not. In this case, managing for early successional habitats means that wildlife dependent on mid- and late-successional habitats will not benefit.

## CONCLUSION

Conducting studies of management treatments in natural settings can be very challenging. Wildlife managers face many uncontrollable obstacles that can sideline even the best planned management studies. Finding suitable controls is difficult at best and sometimes impossible. Resolving biologically relevant patterns with statistical techniques in the face of unbalanced statistical designs, high amounts of temporal and spatial variability, and achieving enough replication to produce generalizable results provide additional challenges. Nevertheless, adaptive management requires that we study management and identify ways that we can improve. We attempted to do just that and identified some key differences in Sharp-tailed Grouse responses to fall prescribed fire and mechanical treatments. These differences may have been significantly influenced by the management treatments but may have also been confounded by the landscape context or the size of the treated sites. However, in our study system in Minnesota, these three factors are unlikely to be easily separated because of the constraints of working in real landscapes. In Minnesota, the landscape is fragmented by agriculture and ownership is parceled into small acreages compared to elsewhere in Sharp-tailed Grouse range. The management treatment applied was likely influenced by the practicalities of working in these landscapes. Fire is more easily implemented at large sites in more contiguous landscapes. In more fragmented landscapes, mowing and shearing may be more feasible, but at some point, management treatment of any kind may become ineffective due to a scarcity of surrounding habitat to meet habitat thresholds needed to support Sharp-tailed Grouse. We did not find any evidence of a Sharp-tailed Grouse response to mowing and shearing in our study, nor did we see a pattern suggestive of a response, although larger sample sizes would improve statistical power. It is prudent that researchers identify habitat thresholds below which management is unlikely to be effective. Redirection of limited resources to areas more likely to produce a response because of proximity to habitat thresholds, or exceedance of habitat thresholds, may have the best likelihood of success for area-sensitive species like the Sharp-tailed Grouse in the Great Lakes Region.

**Acknowledgments:**

*We thank area wildlife managers, assistant managers, and staff at Baudette, Karlstad, Red Lake Wildlife Management Area (WMA), Roseau River WMA, Thief River Falls, and Thief Lake WMA. J. Eerkes at The Nature Conservancy helped identify sites and conduct management. We thank our seasonal technicians M. Schleif, V. Johnson, J. Colbaugh, A. Mosloff, A. Erickson, J. Brunner, A. Del Valle, L. Hause, N. Benson, M. McBride, K. Macco-Webster, and S. Burns. P. Coy assisted with data collection in the field and with data management. C. Scharenbroich assisted with preparation of GPS units for field use. Funding for this study was provided by the Wildlife Restoration (Pittman-Robertson) Program. We also thank E. Blomberg, D. Musil, and an anonymous reviewer for helpful comments on the manuscript.*

**Data Availability:**

*Data are archived by the Minnesota Department of Natural Resources.*

## LITERATURE CITED

Ammann, G. A. 1957. The Prairie Grouse of Michigan. Michigan Department of Conservation Technical Bulletin. Michigan Department of Conservation, Lansing, Michigan, USA.

Bates, D., M. Mächler, B. Bolker, and S. Walker. 2015. Fitting linear mixed-effects models using lme4. Journal of Statistical Software 67(1). https://doi.org/10.18637/jss.v067.i01

Berg, W. E. 1997. The Sharp-tailed Grouse in Minnesota. Minnesota Wildlife Report 10, Minnesota Department of Natural Resources, St. Paul, Minnesota, USA. https://files.dnr.state.mn.us/recreation/hunting/grouse/grouse_in_mn.pdf

Brooks, M. E., K. Kristensen, K. J. van Benthem, A. Magnusson, C. W. Berg, A. Nielsen, H. J. Skaug, M. Mächler, and B. M. Bolker. 2017. glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. R Journal 9:378-400. https://doi.org/10.32614/RJ-2017-066

Brown, J. K., and J. K. Smith, editors. 2000. Wildland fire in ecosystems: effects of fire on flora. General Technical Report RMRS-GTR-42 vol 2. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, Utah, USA. https://doi.org/10.2737/RMRS-GTR-42-V2

Campomizzi, A. J., J. A. Butcher, S. L. Farrell, A. G. Snelgrove, B. A. Collier, K. J. Gutzwiller, M. L. Morrison, and R. N. Wilkins. 2008. Conspecific attraction is a missing component of wildlife habitat modeling. Journal of Wildlife Management 72:331-336. https://doi.org/10.2193/2007-204

Connelly, J. W., M. W. Gratson, and K. P. Reese. 2020. Sharp-tailed Grouse (*Tympanuchus phasianellus*), version 1.0. In A. F. Poole and F. B. Gill, editors. Birds of the world. Cornell Lab of Ornithology, Ithaca, New York, USA.

Connolly, T. T. 2001. Reproductive ecology of Sharp-tailed Grouse in the pine barrens of northwestern Wisconsin. Thesis. University of Wisconsin, Stevens Point, Wisconsin, USA. https://minds.wisconsin.edu/handle/1793/80788

Crosby, A. D., R. D. Elmore, and D. M. Leslie. 2013. Northern Bobwhite response to habitat restoration in eastern Oklahoma. Wildlife Society Bulletin 37:733-740. https://doi.org/10.1002/wsb.351

Dahlgren, D. K., R. Chi, and T. A. Messmer. 2006. Greater Sage-grouse response to sage-brush management in Utah. Wildlife Society Bulletin 34:975-985. https://doi.org/10.2193/0091-7648(2006)34[975:GSRTSM]2.0.CO;2

Evans, S. A., S. M. Redpath, F. Leckie, and F. Mougeot. 2007. Alternative methods for estimating density in an upland game bird: the Red Grouse *Lagopus lagopus scoticus*. Wildlife Biology 13:130-139. https://doi.org/10.2981/0909-6396(2007)13[130:AMFEDI]2.0.CO;2

Fitzgerald, S. M., and G. W. Tanner. 1992. Avian community response to fire and mechanical shrub control in south Florida. Journal of Range Management 45:396-400. https://doi.org/10.2307/4003090

Fox, J., and S. Weisberg. 2019. An R companion to applied regression. Third edition. Sage, Thousand Oaks, California, USA.

Fuhlendorf, S. D., T. J. Hovick, R. D. Elmore, A. M. Tanner, D. M. Engle, and C. A. Davis. 2017. A hierarchical perspective to woody plant encroachment for conservation of Rrairie-chickens. Rangeland Ecology and Management 70:9-14. https://doi.org/10.1016/j.rama.2016.08.010

Fulbright, T. E., K. W. Davies, and S. R. Archer. 2018. Wildlife responses to brush management: a contemporary evaluation. Rangeland Ecology and Management 71:35-44. https://doi.org/10.1016/j.rama.2017.07.001

Grange, W. B. 1948. Wisconsin grouse problems. Wisconsin Department of Conservation, Madison, Wisconsin, USA.

Gratson, M. W. 1988. Spatial patterns, movements, and cover selection by Sharp-tailed Grouse. Pages 158-192 in A. T. Bergerud and M. W. Gratson, editors. Adaptive strategies and population ecology of Northern Grouse. University Minnesota Press, Minneapolis, Minnesota, USA.

Hamerstrom, Jr., F. N., and F. Hamerstrom. 1951. Mobility of the Sharp-tailed Grouse in relation to its ecology and distribution. American Midland Naturalist 46:174-226. https://doi.org/10.2307/2421952

Hanser, S. E, C. L. Aldridge, M. Leu, M. M. Rowland, S. E. Nielsen, and S. T. Knick. 2011. Greater Sage-grouse: general use and roost site occurrence with pellet counts as a measure of relative abundance. Pages 112-140 in S. E. Hanser, M. Leu, S. T. Knick, adn C. L. Aldridge, editors. Sagebrush ecosystem conservation and management. Allen Press, Lawrence, Kansas, USA. https://pubs.usgs.gov/ja/70175386/70175386.pdf

Higgins, K. F., A. D. Kruse, and J. L. Piehl. 1987. Effects of fire in the northern great Plains. Open Prairie. Extension circulars. Paper 429. https://openprairie.sdstate.edu/cgi/viewcontent.cgi?article=1437&context=extension_circ

Kirsch, L. M., and A. D. Kruse. 1973. Prairie fires and wildlife. Proceedings of the Tall Timbers Fire Ecology Conference 12:289-303.

Knapp, E. E., B. L. Estes, and C. N. Skinner. 2009. Ecological effects of prescribed fire season: a literature review and synthesis for managers. General Technical Report PSW-GTR-224. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Ogden, Utah, USA. https://doi.org/10.2737/PSW-GTR-224

Knosalla, L. 2019. Seasonal prescribed burning impacts to northern Minnesota lowland brush ecosystem plant communities. Thesis. University of Minnesota, Twin Cities, Minnesota, USA. https://conservancy.umn.edu/handle/11299/206700

Komarek, E. V. Sr. 1969. Fire and animal behavior. Pages 160-207 in E. V. Komarek. Proceedings Tall Timbers Fire Ecology Conference No. 9. Tall Timbers Research Station, Tallahassee, FLorida, USA.

Krobinger, G. D. 1980. Habitat use by nesting and brooding Sharp-tailed Grouse in southwestern North Dakota. North Dakota Outdoors 43:2-6.

Kruse, A. D., and K. F. Higgins. 1990. Effects of prescribed fire upon wildlife habitat in northern mixed-grass prairie. Pages 182-193 in M. E. Alexander, and G. F. Bisgrove, editors. The art and science of fire management: proceedings of 1st Interior West Fire Council Annual Meeting and Workshop, Kananaskis Village, Alberta, Canada. Report NOR-X-309. Forestry Canada, Northwest Region, Northern Forestry Centre, Edmonton, Alberta, Canada.

Lenth, R. V. 2022. Emmeans: estimated marginal means, aka least-squares means. R package version 1.7.3. R Foundation for Statistical Computing, Vienna, Austria. https://cran.r-project.org/web/packages/emmeans/emmeans.pdf

Levy, E. B., and E. A. Madden. 1933. The point method of pasture analysis. New Zealand Journal of Agriculture 46(5):267-179.

Morrison, M. L., W. M. Block, M. D. Strickland, and B. A. Collier. 2001a. Wildlife study design. Springer-Verlag, New York, New York, USA.

Morrison, M. L. 2001b. A proposed research emphasis to overcome the limits of wildlife-habitat relationship studies. Journal of Wildlife Management 65:613-623. https://doi.org/10.2307/3803012

Niemuth, N. D., and M. S. Boyce. 2004. Influence of landscape composition on Sharp-tailed Grouse lek location and attendance in Wisconsin pine barrens. Écoscience 11(2):209-217. https://doi.org/10.1080/11956860.2004.11682826

Prose, B. L. 1987. Habitat suitability index models: plains Sharp-tailed Grouse. US Fish and Wildlife Service Biological Report 82. National Ecology Center, Washington D.C., USA.

R Core Team. 2022. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Rippin, A. B., and D. A. Boag. 1974. Spatial organization among male Sharp-tailed Grouse on arenas. Canadian Journal of Zoology 52:591-597. https://doi.org/10.1139/z74-077

Robel, R. J., J. N. Briggs, A. D. Dayton, and L. C. Hulbert. 1970. Relationship between visual obstruction measurements and weight of grassland vegetation. Journal of Range Management 23:295:297. https://doi.org/10.2307/3896225

Roy, C. 2022. 2022 Minnesota Sharp-tailed Grouse survey. Minnesota Department of Natural Resources Report. Forest Wildlife Populations and Research Group Minnesota Department of Natural Resources, Grand Rapids, Minnesota, USA. https://files.dnr.state.mn.us/wildlife/grouse/reports/sharptail/stail_survey_2022.pdf

Savory, C. J. 1978. Food consumption of Red Grouse in relation to the age and productivity of heather. Journal of Animal Ecology 47:269-282. https://doi.org/10.2307/3935

Schroeder, M. A., and W. M. Vander Haegen. 2014. Monitoring of Greater Sage-Grouse and other breeding birds on the Withrow Wind Power Project Site: final report. Washington Department Fish and Wildlife, Olympia, Washington, USA. https://wdfw.wa.gov/sites/default/files/publications/01607/wdfw01607.pdf

Sexton, D. A., and M. M. Gillespie. 1979. Effects of fire on the location of a Sharp-tailed Grouse arena. Canadian Field Naturalist 93:74-76.

Smith, E. P. 2002. BACI design. Pages 141-148 in A. H. El-Shaarawi and W. W. Piegorsch, editors. Encyclopedia of Environmetrics. Vol. 1. John Wiley and Sons, Chichester, UK.

Thompson, S. K. 2002. Sampling. Second edition. John Wiley and Sons, New York, New York, USA.

Van Horne, B. 1983. Density as a misleading indicator of habitat quality. Journal of Wildlife Management 47:893-901. https://doi.org/10.2307/3808148

Vogl, R. J. 1973. Effects of fire on the plants and animals of a Florida wetland. American Midland Naturalist 89:334-347. https://doi.org/10.2307/2424038

Zar, J. H. 1996. Biostatistical analysis. Third edition. Prentice Hall, Upper Saddle River, New Jersey, USA.

Editor-in-Chief: Judit K. Szabo
Subject Editor: Erik Blomberg

Sponsored by the Society of Canadian Ornithologists and Birds Canada

*Parrainée par la Société des ornithologistes du Canada et Oiseaux Canada*