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PRACTICE INSIGHTS

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Large-scale fire management restores grassland bird richness for a private lands ecoregion

Caleb P. Roberts[1] | Rheinhardt Scholtz[2] | Dillon T. Fogarty[2] | Dirac Twidwell[2] | Thomas L. Walker Jr.[3]

[1] U.S. Geological Survey, Arkansas Fish and Wildlife Cooperative Research Unit, University of Arkansas, Fayetteville, Arkansas, USA

[2] Department of Agronomy and Horticulture, University of Nebraska–Lincoln, Lincoln, Nebraska, USA

[3] Nebraska Game and Parks Commission, Lincoln, Nebraska, USA

Correspondence
Caleb P. Roberts, U.S. Geological Survey, Arkansas Fish and Wildlife Cooperative Research Unit, University of Arkansas, 850 W Dickson St, SCEN 522, Fayetteville, AR 72701, USA.
Email: cr065@uark.edu

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Abstract

1. Of all terrestrial biomes, grasslands are losing the most biodiversity the most rapidly, so there is a critical need to document and learn from large-scale restoration successes.
2. In the Loess Canyons ecoregion of the Great Plains, USA, an association of private ranchers and natural resource agencies has led a multi-decadal, ecoregion-scale initiative to combat the loss of grasslands to woody plant encroachment by restoring large-scale fire regimes. Here, we use 14 years of fire treatment history with 6 years of grassland bird monitoring and remotely sensed tree cover data across 136,767 ha of privately owned grassland to quantify outcomes of large-scale grassland restoration efforts.
3. Grassland bird richness increased across 65% (90,032 ha) of the Loess Canyons, and woody plant cover decreased up to 55% across 25% (7408 ha) of all fire-treated areas.
4. This was accomplished with extreme fire treatments that killed mature trees, were large (mean annual area burned was 3100 ha), spatially clustered and straddled boundaries between invasive woodlands and remaining grasslands – not heavily infested woodlands.
5. Findings from this study provide the first evidence of human management reversing the impacts of woody encroachment on grassland birds at an ecoregion scale.

KEYWORDS
adaptive management, invasive species, juniper, prescribed fire, resilience, woody plant encroachment

1 | INTRODUCTION

In grasslands, documentation of successful large-scale restoration strategies is critical for adapting strategies in this era of global change (Augustine et al., 2019). Of all the world's biomes, grasslands have lost the greatest amount of biodiversity (Newbold et al., 2016). In North America, grassland birds are the flagship taxa for losses in grassland diversity: they are experiencing the sharpest declines of all bird guilds (Rosenberg et al., 2019). Many factors contribute to declines in grassland birds, including conversion of grasslands to row crop agriculture, energy development and urbanization (Rosenberg et al., 2019). But one of the strongest drivers, especially for lands not lost to human development, is woody plant encroachment (Andersen & Steidl, 2019).

Restoring fire to landscapes is one of the most effective methods to halt and reverse woody plant encroachment and restore grassland avifauna (Fuhlendorf et al., 2006). Fire is a critical negative feedback that formed and maintained grasslands globally (Twidwell, Rogers, et al., 2016). However, due to barriers to fire usage imposed by the fact that grasslands are extremely fragmented and most are privately owned, implementing fire restoration beyond the scale of individual pastures or tracts of publicly owned lands is difficult (Augustine et al., 2019). Laws and policies such as widespread fire suppression, narrow ranges of conditions under which prescribed fires are allowed to burn and financial liability resultant from property lost to prescribed fire also create barriers for fire usage (Twidwell, West, et al., 2016; Wonkka et al., 2015). This has led to documentation of local restoration successes, but ecoregion-scale successes have been lacking (Garmestani et al., 2020).

In the Loess Canyons ecoregion of the Great Plains, USA, the threat of woody encroachment to both biodiversity and grassland productivity has motivated an ecoregion-scale restoration initiative led by private ranchers with support from natural resource agencies. To address the scale of this threat, managers have adopted high-intensity fire treatments as a large-scale restoration tool to benefit grassland biodiversity and productivity (Twidwell et al., 2013). Evidence is accumulating for the successfulness of large-scale, high-intensity fire treatments in halting woody plant encroachment and restoring grassland productivity (Bielski et al., 2021; Fogarty et al., 2020). However, large-scale outcomes for grassland biodiversity have not been documented.

Here, we use 14 years of fire treatment history with 6 years of grassland bird monitoring and remotely sensed tree cover data across a 136,767-ha ecoregion to assess grassland restoration outcomes and glean practical lessons. Our objectives are to (1) summarize fire treatment patterns and effects on woody plant cover, and (2) quantify spatiotemporal responses of grassland bird richness to woody plant cover change and fire treatments.

2 | MATERIALS AND METHODS

2.1 | Study site

The Loess Canyons ecoregion in Nebraska, USA is a priority conservation landscape in the Nebraska State Wildlife Action Plan because it supports many at-risk grassland species (Schneider et al., 2005). Historically, mixed-grass prairie dominated the Loess Canyons, woodlands were rare and fire return intervals were 6–8 years (Guyette et al., 2012). But fire suppression and tree planting became dominant practices in the Loess Canyons (Roberts et al., 2018). Consequently, between 2000 and 2010 (start of bird surveys), woodlands increased from 3% to 10% of the area of the Loess Canyons (Fogarty et al., 2020).

In 2002, a collaboration between private landowners, natural resource agencies and universities formed the Loess Canyons Experimental Fire Landscape. To combat woody plant encroachment, collaborators have applied large-scale extreme fire treatments nearly every year across property ownership boundaries in the ecoregion (Bielski et al., 2021). Two landowner-led prescribed burn associations with landholdings representing most of the ecoregion drive fire treatments. Fuels are often manipulated (e.g. trees along woodland edges are 'cut and stuffed' under neighbouring trees the winter before a fire treatment to create ladder fuels) and weather conditions targeted (e.g. low humidity, high temperatures) to implement fires in conditions that exceed juniper mortality thresholds and thus increase the likelihood of restoring grassland from woodland dominance (Bielski et al., 2021). Fire treatments are mainly conducted during spring months, prior to bird breeding season.

2.2 | Data collection

2.2.1 | Grassland bird richness

We conducted roadside breeding bird point-count surveys along nine established routes for 6 years (2010–2014 and 2016). Routes consisted of 50 point-count survey stops evenly spaced along 39 km. We used one North American Breeding Bird Survey (BBS) route (54035 Brady), and the Nebraska Game and Parks Commission created the remaining eight routes (Figure S1). We designed routes to document change in bird diversity over time in response to management activities and to cover as much of the Loess Canyons as possible. For Nebraska Game and Parks Commission routes, we followed BBS methodology (Sauer et al., 2017) with two exceptions: we started Nebraska Game and Parks Commission routes 45 min before sunrise (BBS routes begin 30 min before sunrise), and we surveyed some routes in some years outside the BBS date window (27 May–7 July), but all surveys were conducted within local breeding seasons. A single trained observer (Thomas L. Walker Jr.) conducted all surveys. To calculate grassland bird richness, we only considered observed species whose primary habitat is grassland (Table S1).

2.2.2 | Tree cover

We quantified tree cover via the Rangeland Analysis Platform (RAP) annual continuous vegetation cover dataset (Allred et al., 2021). The RAP provides subpixel percent cover of various vegetation functional groups, such as tree cover (2.8% mean absolute error). To match the scale of bird point count sampling, we calculated mean percent tree cover within a 400-m radius of each bird survey stop.

2.2.3 | Fire treatment data

We included all fires that occurred from the beginning of large-scale fire treatments through the end of the bird surveys (2002–2016) in our analyses. We did not differentiate between fire treatments and wildfires. We obtained fire treatment area, boundaries and dates from

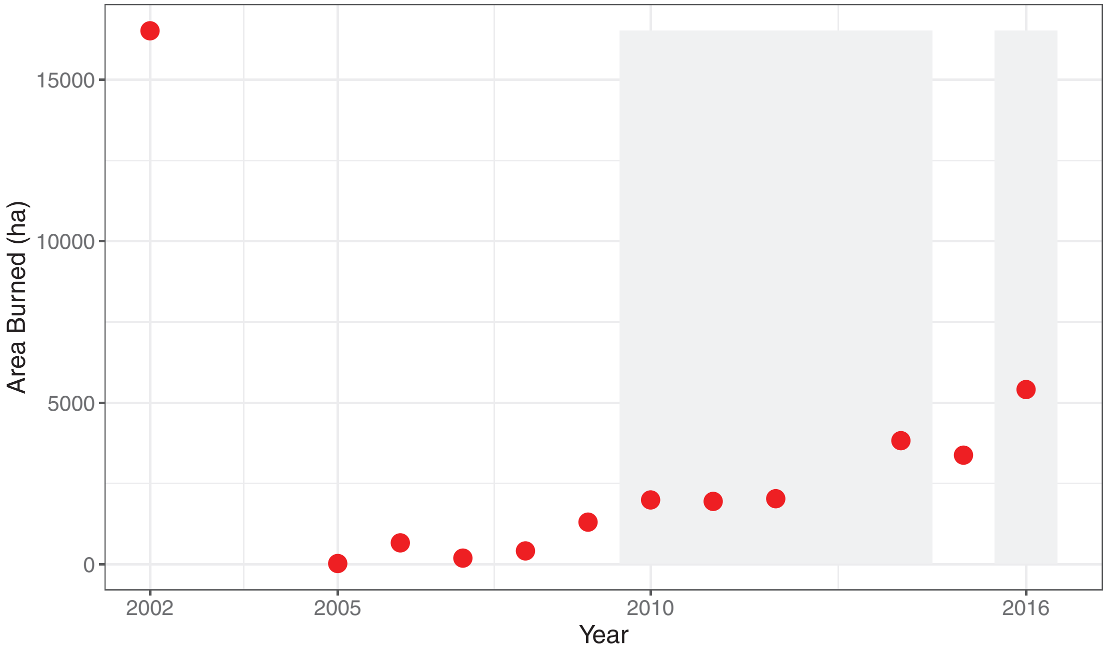

FIGURE 1 Trend in annual area receiving fire treatments in the Loess Canyons, Nebraska, USA from 2002 to 2016. Red dots indicate yearly hectares burned. The greyed area corresponds with years bird surveys occurred

Loess Canyons ranchers, and we retrieved the same data for the single wildfire that occurred during the study (2002 Gothenburg Wildfire) from the Monitoring Trends in Burn Severity database (Eidenshink et al., 2007). For each bird survey stop, we determined if it fell within a fire treatment and then calculated years-since-fire for each year of the study.

2.3 | Analysis

2.3.1 | Summarize fire treatment patterns and effects on woody plant cover

We summarized temporal fire treatment patterns by summing the hectares burned each year. We summarized spatial fire treatment patterns by mapping fire treatment and wildfire perimeters.

We characterized fire treatment effects on woody plant cover by subtracting the 2010 mean percent tree cover from the 2016 mean percent tree cover in each 400 x 400 m pixel. Because tree cover mean absolute error was 2.8%, we categorized pixels with >|3%| change in tree cover as significantly increasing or decreasing.

2.3.2 | Quantify response of grassland bird richness to woody plant cover change and fire treatments

We quantified responses of grassland bird richness to woody plant cover change and fire treatments in two modelling steps (see Methods in Appendix S1 for full details). First, we predicted grassland bird richness across a continuous surface. To do this, we set grassland bird richness as the response variable in a hierarchical generalized additive model (HGAM). We then created three predictors: (1) a three-way interaction term using time (year) and bird survey stop spatial coordinates to estimate nonlinear spatiotemporal patterns in grassland bird richness, (2) a smoothed predictor term using mean percent tree cover within 400 m of bird survey stops to estimate nonlinear responses of grassland bird richness to woody plant cover and (3) a smoothed random effect for survey routes to account for differences in survey days.

Second, we quantified how change in grassland bird richness responded to change in woody plant cover and fire treatments. To do this, we set change in predicted grassland bird richness (richness in 2016 minus richness in 2010) as the response variable in a generalized additive model (GAM), and we created a two-way interaction predictor term using change in mean percent tree cover (i.e. tree cover in 2016 minus tree cover in 2010) and years-since-fire.

3 | RESULTS

3.1 | Summarize fire treatment patterns and effects on woody plant cover

From 2002 to 2016, average fire size was 283 ha, and fire size ranged from 9 to 1041 ha (Figure 1). Annual area burned was highest in 2002, when the Gothenburg wildfire burnt 15,972 ha alone (~10% of the Loess Canyons), and fire treatments totalled 538 ha. No fires occurred in 2003–2004. From 2005 onward, annual area treated increased. Between 2010 and 2016, annual area treated nearly tripled: in 2010, 1995 ha received fire treatments, and in 2016, 5411 ha received fire treatments, meaning the annual area treated increased from 1% to 4% of the total area of the Loess Canyons.

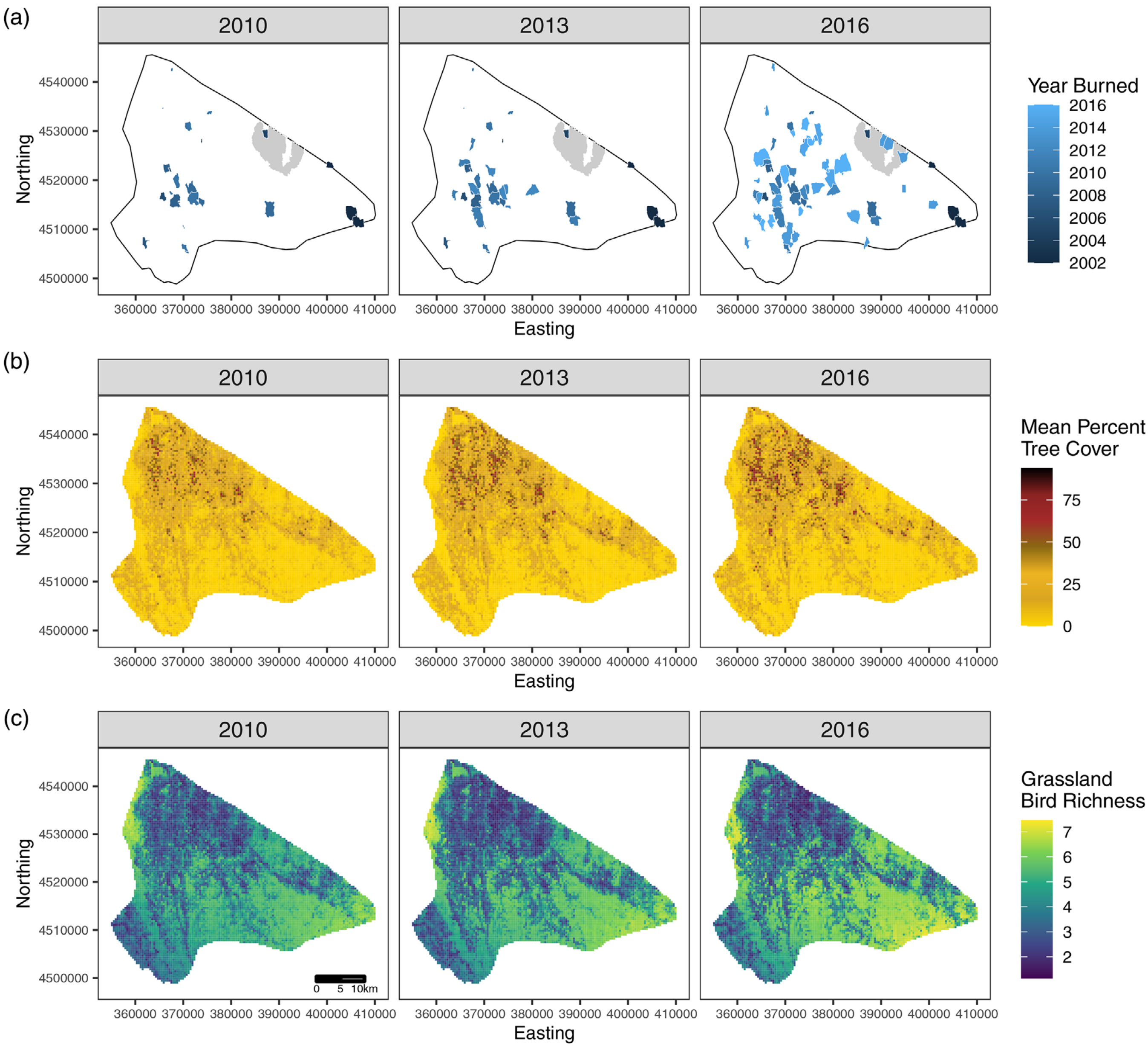

FIGURE 2 Maps of (a) fire treatments, (b) mean percent tree cover per 400 m × 400 m (16 ha) pixel and (c) predicted grassland bird species richness per 400 m × 400 m pixel from 2010 to 2016 in the Loess Canyons, Nebraska, USA. Fire treatment locations in panel (a) are indicated by polygons, and the grey polygon indicates the 2002 Gothenburg wildfire

Spatially, fire treatments were clustered and straddled boundaries between tree-infested areas and grassland strongholds (Figure 2). Several treatments were 'reburns', with some covering previous burns and some covering portions of the Gothenburg wildfire.

Where fire treatments occurred, tree cover declined more and across more area than in untreated areas (Figure 3a; Table S2). Tree cover significantly decreased across 25% of treated areas (6032 ha) compared to 7% (7408 ha) of untreated areas. Tree cover significantly increased in only 19% (4704 ha) of treated areas, whereas tree cover increased in 39% (43,808 ha) of untreated areas. The amount of area where tree cover did not change was similar in treated (56%) and untreated areas (55%).

3.2 | Quantify response of grassland bird richness to woody plant cover change and fire treatments

The HGAM (40.3% deviance explained) revealed that from two areas of high richness – the far western and south-eastern portions of the Loess Canyons – grassland bird richness both moved and increased in eastward and westward trajectories, respectively (Table S3; Figures 2c and S2). As expected, where tree cover increased, grassland bird richness decreased (Figure S3).

Across the entire Loess Canyons (treated and untreated areas), grassland bird richness increased across 90,032 ha (65% of the ecoregion), and richness increased by >1 species across 17,808 ha

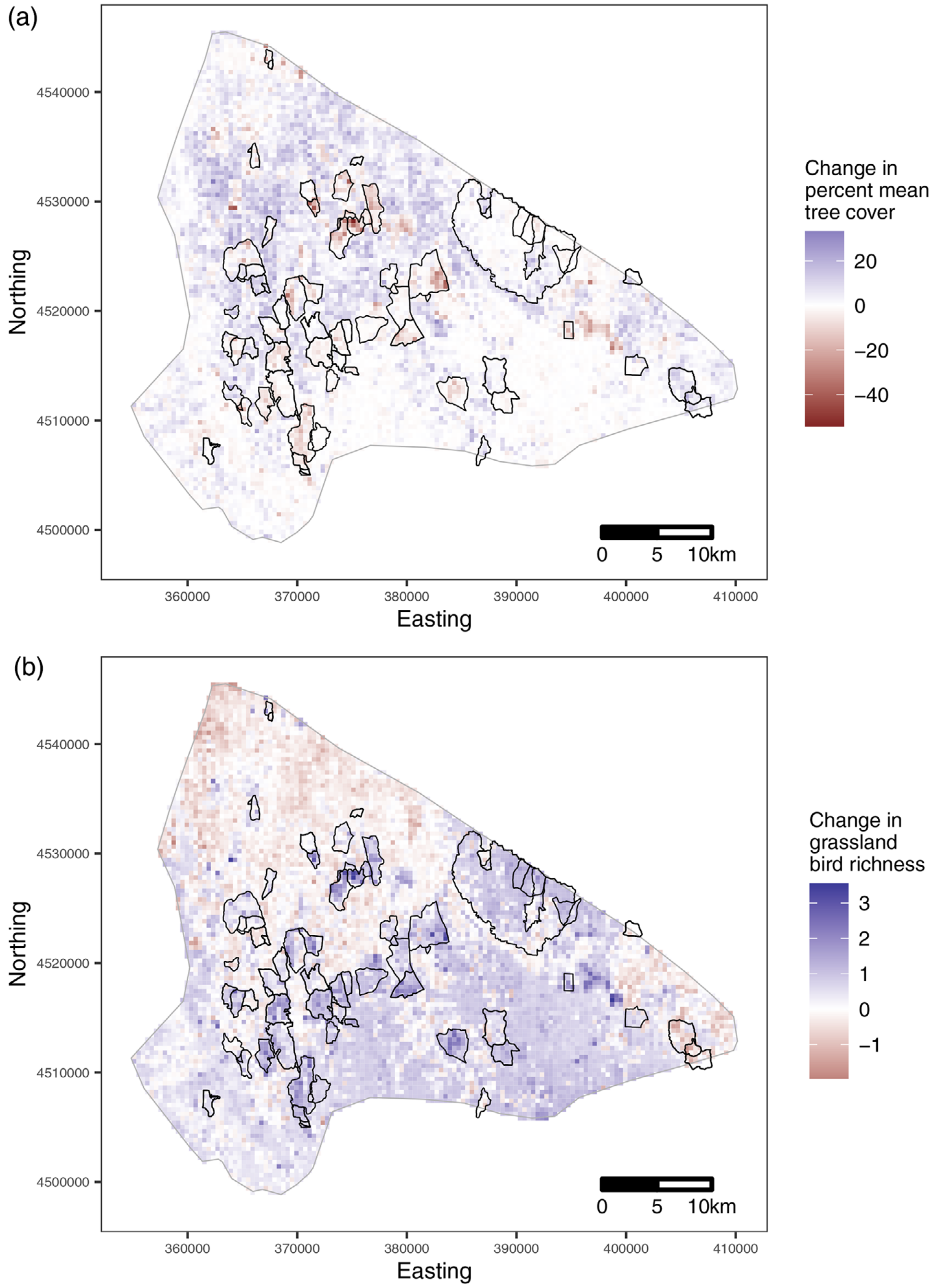

FIGURE 3 Maps of change in (a) mean percent tree cover per 400 m × 400 m pixel (16 ha) and (b) predicted grassland bird species richness per 400 m × 400 m pixel between 2010 and 2016 in the Loess Canyons, Nebraska, USA. Fire treatment locations are indicated by polygons

(13% of the ecoregion; Table S4). Proportionally, grassland bird richness increased more in fire treated areas (85% of treated areas) than in untreated areas (61% of untreated areas; Figure 3). Richness increased most where fire treatments strongly reduced woody plant cover and where woody plant cover was already low. Additionally, the GAM (72.3% deviance explained) revealed that where tree cover was reduced by 20%–55%, grassland bird richness increased by >2 species at 2–3 years post-fire (Figure S4; Table S5).

4 | DISCUSSION

Large-scale fire treatments increased grassland bird richness in a 136,767-ha ecoregion dominated by private lands. Given that grassland bird richness increased in both fire-treated and untreated areas, unmodeled factors (e.g. mechanical tree removal, grazing practices) also likely contributed to increases in richness (Fuhlendorf et al., 2006). Nevertheless, we provide strong evidence that this conservation success was accomplished by a grassroots collaboration between private landowners and natural resource agencies implementing large and intense fires that killed mature trees and restored grasslands. This bucks the trend of global declines in grassland biodiversity (Newbold et al., 2016) and contrasts the sharp losses in grassland bird abundance and diversity throughout North America (Rosenberg et al., 2019).

Practical takeaways from this study derive from the spatial attributes, scale and context of the fire treatments. Fire treatments were large, contiguous and straddled boundaries between invasive woodlands and remaining grasslands. Between 2010 and 2016, mean annual area burned was 3100 ha. Fire treatments were clustered, and fires were set not in heavily infested areas but in areas in and surrounding core grassland strongholds. These tactics address limitations noted in other grassland restoration efforts that led to small or no gains in grassland bird diversity – such as treating isolated patches, small-scale treatments and relying only on public lands for restoration success (Augustine et al., 2019; Lituma & Buehler, 2020). Additionally, fire treatments covered multiple landowners' properties and included several reburns of previously treated areas. Fire treatments used 'extreme' fire intensities capable of killing woody plants at all stages of their life cycles from the seed banks to mature trees (>10 m tall; Garmestani et al., 2020; Twidwell, West, et al., 2016). Notably, the burn association opportunistically used a wildfire to build a grassland core: they set reburns inside the wildfire perimeter and new treatments adjacent to it.

Coupled with these fire treatment tactics, use of social strategies reflecting the philosophy of 'thinking like a grassland' catapulted grassland management from local-scale to ecoregion-scale success (Augustine et al., 2019). To illustrate – since its creation, the Loess Canyons' prescribed burn associations have actively communicated and partnered with neighbours, the state prescribed fire council and natural resource agencies. The associations also consistently document and publicize their successes (e.g. Twidwell, 2021). This collaboration between private and public landowners and constant, demonstrable success allowed large grassland tracts to be 'stitched together' via cross-boundary restoration of large-scale fire – the fundamental process that creates and maintains grasslands (Fuhlendorf et al., 2006). Further, these social strategies facilitated constant increases in funding, people power, scope and expertise. This further increased the scale of management and success (Twidwell et al., 2013).

Recent developments in resilience theory suggest large-scale, spatially explicit grassland restoration strategies will be the most cost-effective and ecologically impactful (Allen et al., 2016). This is because the resilience of grasslands is tied to spatial processes and responses. For example, woody plant encroachment is a spatially contagious process, and via new remote sensing methods, high-risk propagule sources can be identified, tracked in space and targeted for restoration (Uden et al., 2019). Similarly, grassland birds are sensitive to small increases in woody plants at broad scales, require large-scale, treeless grasslands to maintain viable populations and respond to stressors (e.g. woody plant encroachment) and restoration actions (e.g. conifer removal) in a spatially predictable fashion (Andersen & Steidl, 2019; Olsen et al., 2021). To illustrate, we show grassland bird richness increased in untreated/unburned areas (albeit not to the same magnitude as in treated areas), but untreated/unburned areas with increases lay almost exclusively within pre-existing core grasslands adjacent to fire treatments. In contrast, in heavily infested areas, richness changed little or none outside of treatment boundaries. Together, the evidence suggests targeted grassland restoration focusing on preventing woody plant encroachment in intact grassland cores and restoring grasslands at boundaries between grasslands and invasive woodlands will be most successful in conserving and increasing grassland bird diversity.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

CPR, DT, RS, DF and TW conceived and designed the research. TW and DF collected the data. CPR and RS analysed the data. All authors wrote and edited the manuscript.

PEER REVIEW

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DATA AVAILABILITY STATEMENT

Reproducible computer code, all tree cover data, summarized bird survey and summarized fire history data are available in Zenodo: https://doi.org/10.5281/zenodo.5715157 (LivingLandscapes, 2021).

ORCID

Caleb P. Roberts https://orcid.org/0000-0002-8716-0423

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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