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UN DECADE ON ECOSYSTEM RESTORATION

Data Article

Mapping fire history and quantifying burned area through 35 years of prescribed fire history at an Illinois tallgrass prairie restoration site using GIS

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Abstract

1. Fire was important to pre-colonization prairies. In today's remnant and reconstructed prairies, managers frequently employ prescribed fire, a historical management practice that limits woody encroachment, suppresses non-native species and promotes nutrient cycling. However, few long-term prescribed fire spatial datasets are available for study.
2. We used archived images of prescribed fire maps and hand-drawn fire records to generate a geospatial record of the prescribed fire history at Nachusa Grasslands, a combination remnant and restored preserve in northern Illinois.
3. This record contains maps of the prescribed fire history of the preserve across the entirety of its 35-year history. We used the maps to calculate both the absolute area and percentage of the preserve burned every year.
4. This dataset compiles a long history of prescribed fire on a nature preserve and, due to the existing robust research programme at the preserve, can support the study of patterns in management applications of prescribed fire and examine the impacts of prescribed fire in restoration projects.

KEYWORDS
disturbance, prescribed fire, spatial ecology, tallgrass prairie

1 | INTRODUCTION

Prescribed fire is a practice that has been present in some form on the tallgrass prairies of North America since well before European colonization. These pre-colonization fires, often intentionally set by indigenous peoples, aided in the management of bison movements on the prairie (Transeau, 1935). These fires also served the secondary purpose of limiting the encroachment of woody vegetation. As a result of colonization, industrialization and urbanization, Indigenous communities were removed from the land and fire suppression became a common practice (Courtwright, 2007). The vast majority of tallgrass prairies were converted to farmland, and other stretches were invaded by woody species that thrived under fire suppression (DeSantis et al., 2011). Today in Illinois, only 1% of historical tallgrass prairie remains, making it one of the world's most at-risk ecosystems (Howe, 1994). Many land managers of remnant (never plowed) and reconstructed

prairies now use prescribed fire as a practice to help support plant diversity (Bowles & Jones, 2013) and manage woody encroachment (DeSantis et al., 2011) in an attempt to replicate the impacts of the fire regime present in pre-colonization prairies. As a result, a large portion of tallgrass prairie research focuses on understanding the impacts of prescribed fire on all aspects of prairie communities and their functioning. In restored ecosystems, comprehensive, long-term studies of the impacts of fire are especially important to understand fire impacts and predict the outcome of prescribed fire application on restoration progress (Blackburn et al., 2020), but most studies focus on the immediate impacts of fire as studied over short-time periods (Allred et al., 2011; Hovick et al., 2015; Ricketts & Sandercock, 2016). Research on prescribed fire impacts encompasses many different taxa, including plants (Kirchner et al., 2011), birds (Reinking, 2005) and small mammals (Burke et al., 2020), as well as broad ecosystem functioning.

Geographic information systems (GIS) provide a potential avenue for using advanced tools to investigate quantifying the impacts of prescribed fire (Caprio et al., 1997; Duncan et al., 2009). By creating digital maps of burned land, managers and researchers can better understand trends and patterns in the application of fire. Additionally, these maps encourage more in-depth and novel study of prescribed fire outcomes on various taxa. Here, we present data quantifying the amount of prescribed fire at a 35-year-old restored tallgrass prairie using GIS, a step towards the quantification of prescribed fire impacts using spatial analysis. This dataset will help support the plethora of researchers representing 20 institutions who study diverse taxa (mammals, bees, dung beetles, epiphytes, etc.) and ecosystem functioning at the focal preserve. Fire is applied at the discretion of managers and stewards, and detailed records have been kept on the locations of burns each year, though these records were not digitized or put into GIS before our study. Our objective was to put these records into a GIS format to provide a rich dataset, which tracks fire throughout the preserve from its inception to present day. We hope this dataset will enable managers and researchers to investigate patterns with fire quantitatively.

2 | MATERIALS AND METHODS

2.1 | Study site

Nachusa Grasslands, located in Franklin Grove, Illinois (41.89108N, 89.34378W) is an over 1600 hectare tallgrass prairie preserve. The prairie is composed of remnant (land that has never been plowed) and restored (land converted back to prairie after a period of time as agricultural or pasture land) prairie, as well as wetlands, savanna and patches of oak woodlands. Nachusa is owned by The Nature Conservancy (TNC) and is managed by a small staff and a crew of volunteer stewards. The initial land purchase of Nachusa Grasslands, a tract of 160 hectares, was made in 1987 and land acquisition has occurred since then, creating a unique chronosequence of restoration age across the preserve.

Numerous species populate Nachusa Grasslands, including over 700 species of plants and a variety of reptiles, birds and mammals. The communities at Nachusa also include several threatened and endangered species including the eastern prairie fringed orchid (*Platanthera leucophaea*), Blanding's turtle (*Emydoidea blandingii*) and northern harrier (*Circus hudsonius*). In 2014, a herd of bison were reintroduced to approximately one-half of the preserve. The herd is now maintained at approximately 100 individuals.

Prescribed fire is also applied routinely on the preserve. Every burn season, here defined as late fall to mid-spring, taking into account the perspective of the stewards and researchers, managers choose sections of the preserve to burn to enhance prairie restoration quality, prevent woody encroachment and manage invasive plants that are not fire-adapted. There is variation in fire return interval across the preserve and through time, with some sites receiving fire several years in a row and others not receiving fire for several years. Prescribed fire at Nachusa Grasslands is used to meet management objectives. In any given year, managers decide which units are burned and unburned based on where fire can help control and set-back invasive species and meet habitat needs for a variety of plants and animals ranging from rare plants and insects to turtles and birds. It is likely that fire frequency at Nachusa Grasslands does not represent a historical regime, in part because current ecological pressures from invasive species, particularly woody species, did not exist in the same way in the past. Units at Nachusa with greater invasive species pressure receive fire more frequently than high-quality habitats with few invasive species concerns.

2.2 | Mapping of prescribed fire history

We created maps of the historical application of prescribed fire from archival images of maps created at the end of each burn season, as well as a few scans of hand-drawn fire records (Figure 1a). The majority of these records were created at the conclusion of each fire season, and those that were not were compared to other records of fires conducted that year to ensure that only conducted fires were digitized. We georeferenced the images in ArcGIS Pro (Version 2.8.29751) using a shapefile of the preserve boundaries which were visible on the archival images, as well as landmarks such as road intersections and preserve buildings (Figure 1b). Once these images were georeferenced, we used these historical images of fire application to create accurate shapefiles for each year of fire application (Figure 1c). Using the 'Calculate Area' function, we determined total area burned each burn season. These numbers were combined with records of preserve expansion to determine the percentage of the preserve burned every year (Table 1). We also compared the calculations with the estimates of acreage burned as calculated by the staff each year for further validation. All shapefiles were then combined into a single shapefile using the 'Merge' tool. Using the 'Count Overlapping Features' tool, we created a map identifying areas that received high concentrations of prescribed fire throughout the preserve's history. However, there is not currently a spatial layer of the preserves purchase acquisition history, so this layer cannot yet be standardized by time since acquisition and therefore will not be presented here.

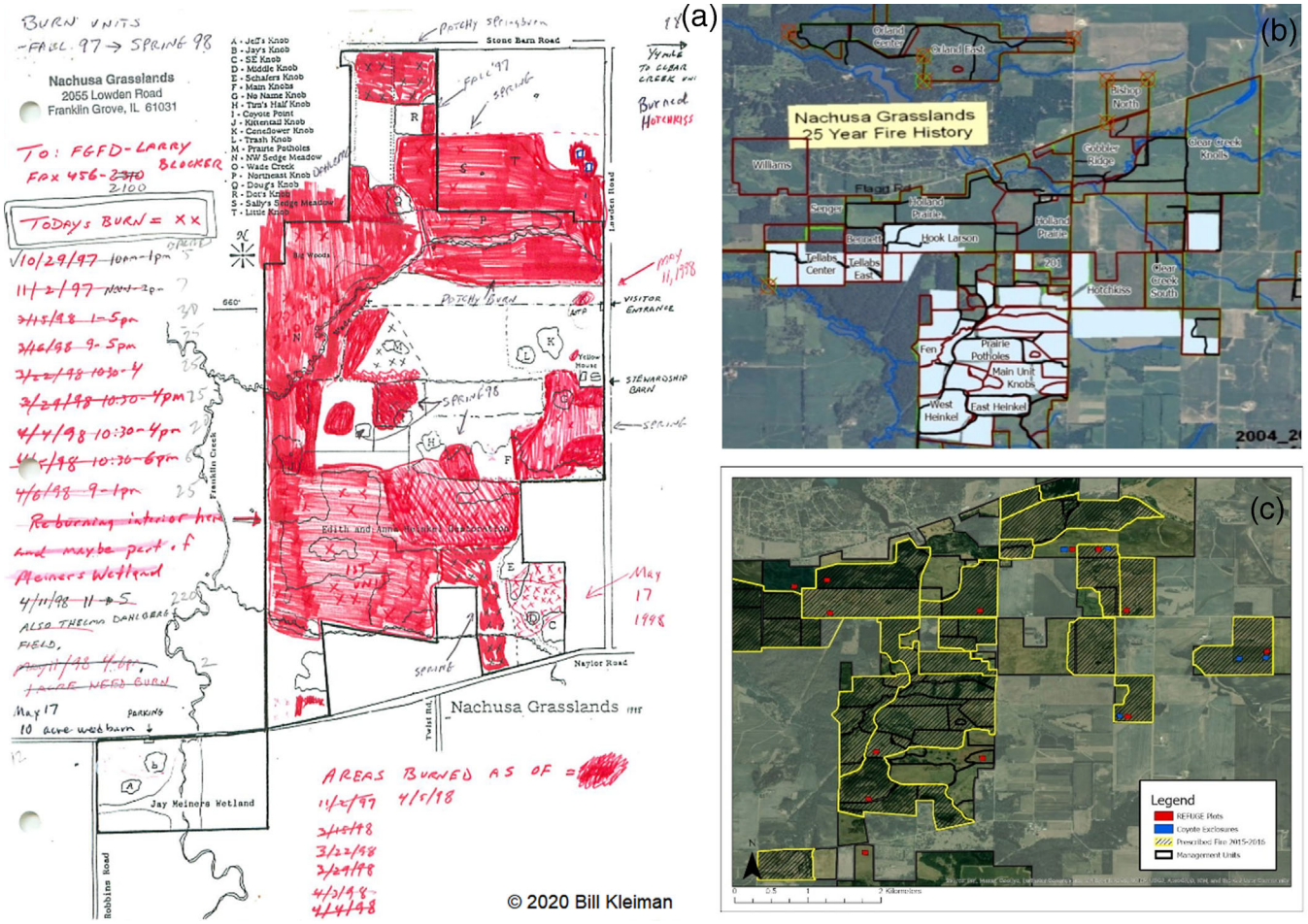

FIGURE 1 (a) An example of a hand-drawn archival map representing the areas of the preserve burned between the fall of 1997 and the spring of 1998. (b) An image demonstrating the georeferencing process for archival images. The overlaid circles and X's represent points that have been selected as reference on both the image and the shapefile. The preserve boundaries in the archive image are shown in green, and the boundaries of the shapefile are shown in brown. (c) An example of the finished fire map product. This map shows the areas that received prescribed fire between fall of 2015 and spring of 2016 and are stored as shapefiles, as well as images, in order for the data to be fully accessible and used in future analysis

3 | USAGE NOTES

These maps were produced in the coordinate system WGS 1984 and projected in NAD 1983 UTM Zone 16N for area calculations. These maps exclude areas that were burned by Nachusa's staff and volunteers outside of the preserve boundaries, either on private land with permission or on land that is managed by the Illinois Department of Natural Resources.

For example, managers regularly burned a plot of land owned by the TNC but not part of Nachusa Grasslands. This burned area was often included in the report as TNC-owned land burned, and no separate figure was given for only the TNC-owned Nachusa Grasslands area burned. Another common source of discrepancy was the inadvertent inclusion of a non-Nachusa area in the shapefiles. This often resulted from an area being burned as private land before being acquired by TNC, and therefore being included as part of Nachusa's burned land a year before it should have. Once these errors were corrected or accounted for, the larger discrepancies were reduced or eliminated.

4 | GENERAL PATTERNS

4.1 | Comparison with manager reports

Calculations of area burned using GIS layers were largely in agreement with the reported figures, with most figures falling within 10 acres of each other. Where larger discrepancies existed, they were discussed with managers to determine the source. Most often, these were due to differences in recording and reporting acreage burned over time.

4.2 | Patterns of prescribed fire application

The area of the preserve that receives prescribed fire has been increasing since the first application in 1986/1987. Not only has the absolute area burned increased over time, but the percentage of the total preserve area burned has increased as well (Figure 2). The proportion of the preserve being burned has increased from 15% in 1986/1987

TABLE 1 A year-by-year breakdown of the acreage burned and the proportion of the preserve that these burns represented

Burn Season	Area burned (hectares)	Preserve area (hectares)	Proportion of preserve burned (%)
1986–1987	24	164	15
1987–1988	25	243	10
1988–1989	55	261	21
1989–1990	22	293	8
1990–1991	91	301	30
1991–1992	125	301	41
1992–1993	0	301	0
1993–1994	70	374	19
1994–1995	106	410	26
1995–1996	167	410	41
1996–1997	240	410	59
1997–1998	180	410	44
1998–1999	235	471	50
1999–2000	191	485	39
2000–2001	163	526	31
2001–2002	300	610	49
2002–2003	362	626	58
2003–2004	324	635	51
2004–2005	423	635	67
2005–2006	298	1027	29
2006–2007	498	1142	44
2007–2008	574	1155	50
2008–2009	567	1172	48
2009–2010	665	1314	50
2010–2011	528	1314	40
2011–2012	774	1354	57
2012–2013	694	1369	51
2013–2014	845	1380	61
2014–2015	583	1473	40
2015–2016	974	1486	66
2016–2017	934	1511	62
2017–2018	904	1529	59
2018–2019	881	1570	56
2019–2020	192	1570	12
2020–2021	931	1617	58

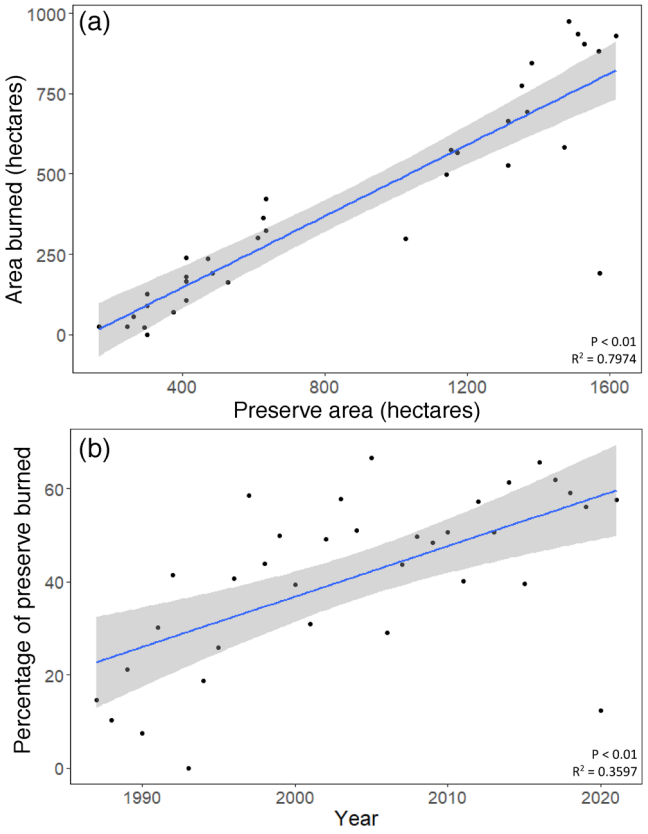

FIGURE 2 (a) As the acreage of the preserve has increased, the area burned has increased as well. This is expected, but as shown in (b), the percentage of the preserve burned has increased over time as the area has increased. This indicates that the increase in acreage burned has not been directly proportional to the increase in preserve area and has instead increased at a faster rate

to 58% in 2020/2021, with an average increase of 1.1% per year. The maximum proportion burned was 423 of 635 hectares (67%) in the 2004/2005 fire season. This maximum was followed by a significant drop to 298 of 1027 hectares (29%) in 2005/2006. This could potentially be attributed to the major growth in preserve between 2004 and 2006, with nearly 400 hectares of new land added in. Setting aside the 1992/1993 fire season, when no prescribed fire was applied, the minimum proportion burned was 22 of 293 hectares (8%) in 1990/1991.

Another noteworthy outlier was the 2019/2020 prescribed fire season. While the previous 4 years had proportions of land burned ranging from 56% to 66%, the 2019/2020 season yielded 192 of 1571 hectares burned for a proportion of 12%, the lowest proportion burned since the 1992/1993 fire season. This was due to limitations on volunteers due to the Covid-19 pandemic. The following burn season, the proportion was much more in line with previous years at 58%, with 931 of 1617 acres burned. This season also had the third highest total area burned in the preserve's history.

4.3 | Applications and future directions

Digital mapping of prescribed fire history provides many unique opportunities for managers and researchers. Researchers and managers at other restoration sites can use this fire history to understand the decision-making process managers use in prescribed fire application and develop frameworks for prescribed fire decision-making. Researchers can also combine these maps with information about

other taxa at Nachusa to conduct more robust analyses of the impacts of prescribed fire on tallgrass prairie organisms, rather than only using time since burn or binary burned and unburned variables, which has until now been the most common practice.

Future work including this specific dataset may include the combination of these maps with the dates of each burn event to assess the weather conditions for the date of each fire. This, in conjunction with observations from practitioners on site, could help provide context about each burn and may serve as an indicator of burn intensity and completeness. Additionally, this dataset could be used in conjunction with assessments of burn intensity derived from satellite imagery and practitioner observations to assess the impacts of burn intensity on ecosystem functioning.

Over time, as this work continues, we hope to add to and expand this dataset. We intend to continue producing digital maps of future fires for use by managers and researchers. We also plan on adding to existing maps by linking them to fire behaviour observations recorded in manager burn records and adding specific date and weather condition information. We are also working to identify areas of high and low fire concentration using this dataset by generating a spatial layer of the expansion of the preserve so that the number of fires in an area can be standardized by the time the area has been a part of the preserve.

As prescribed fire maps become more readily available from multiple restoration sites, managers and researchers can compare patterns in fire application and outcomes across preserves. Widely available digital maps of prescribed fire history may also serve to spark and facilitate informal share of information between managers at different preserves, including discussion on the efficacy of certain prescribed fire patterns and regimes for different management objectives.

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CONFLICT OF INTEREST

Holly Jones is a senior editor of *Ecological Solutions and Evidence* but took no part in the peer review and decision-making process for this paper. Elizabeth Bach is an associate editor of *Ecological Solutions and Evidence* but took no part in the peer review and decision-making process for this paper.

AUTHOR CONTRIBUTION

EGR, EB and HJ conceived the ideas. EGR designed methodology and collected and analysed data. BK produced many of the original maps used in the project and provided insight on prescribed fire history and management. EGR led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

DATA AVAILABILITY STATEMENT

Original data was sourced from existing maps and shapefiles initially created for internal use (The Nature Conservancy, 2019). A map package and individual shapefiles for each fire season are available on Huskie Commons, Northern Illinois University's Institutional Repository (https://huskiecommons.lib.niu.edu/allfaculty-datasets/5/). Data since 2005 is also accessible from the Illinois Fires Accomplished map (https://www.illinoisprescribedfirecouncil.org/illinois-fires-accomplished-map.html), which presents prescribed fire data across the state of Illinois.

PEER REVIEW

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