



Network Scale Fire Atlas Supports Land Management in National Parks

Natural Resource Report NPS/HTLN/NRR—2022/2480



ON THE COVER

Post-burn monitoring photo of long-term vegetation monitoring transect at George Washington Carver National Monument, Diamond, Missouri.

Photography by NPS/HTLN

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Sherry A. Leis

National Park Service
Heartland Inventory and Monitoring Network
Republic, Missouri

Editing and Design by
Tani Hubbard

National Park Service &
Northern Rockies Conservation Cooperative
12661 E. Broadway Blvd.
Tucson, AZ 85748

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Contents

Page

Figures iv

Tables iv

Abstract v

Acknowledgments v

Introduction 1

Methods 3

 Geodatabase development: sources 3

 Geodatabase development: assembly 3

 Geodatabase development: verification and reconciliation 4

 Sources of uncertainty 5

 Spatial uncertainty 5

 Temporal uncertainty 5

 Product development 5

Results 6

Discussion 10

Literature Cited 11

Figures

	Page
Figure 1. Proportion of seven grassland parks in the Heartland Inventory and Monitoring Network where local records indicated that a fire occurred for 1950–2019.	6
Figure 2. Map of fire return interval by burn unit at Pipestone National Monument was developed using the Heartland Inventory and Monitoring Network fire occurrence geodatabase (HFOG)	7
Figure 3. Fire occurrence at vegetation monitoring sites at Effigy Mounds National Monument, Harpers Ferry, Iowa	8
Figure 4. The number of sites burned out of seven during the period 2001–2020 at George Washington Carver National Monument, Diamond, Missouri.	8
Figure 5. Time since fire frequency for six restored tallgrass prairie monitoring sites at Wilson’s Creek National Battlefield, Republic, Missouri	9

Tables

	Page
Table 1. List of sources for fire occurrence information for parks in the Heartland Inventory and Monitoring Network.	4
Table 2. Description of fires contained in the 7-park fire atlas	6

Abstract

Long-term vegetation monitoring allows land managers to make treatment decisions based on data. Fire management is a commonly used approach to managing grasslands, but fire history in grasslands is challenging to record because of spatial and temporal scales and rapid ecosystem recovery. We built a seven-park fire occurrence record (fire atlas) using a geodatabase tool. Multiple sources for fire perimeters were vetted using a verification and editing process. The fire occurrence geodatabase was then used as the basis for an analysis that used buffering around monitoring site locations to determine burned status through time. The resulting products were beneficial for communicating with managers, administrators, and fire staff. Planning and education projects were also important uses of the information. Future efforts will focus on improving attribute consistency and relating vegetation trends to fire occurrence.

Acknowledgments

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Introduction

Vegetation monitoring is an important source of information for natural resource managers within the National Park Service (NPS). Vegetation management is critical to national parks whether vegetation and natural communities are the focus of the park or vegetation plays a supporting role in helping visitors understand the context of important historical people and events. The NPS mandated an emphasis on using science and data as a basis for natural resource decision-making as a result of strong criticism (Leopold et al. 1963; Sellers 1979; NPS 1999, [Natural Resource Challenge, http://npshistory.com/publications/nr-general/nrc/brochure.pdf](http://npshistory.com/publications/nr-general/nrc/brochure.pdf)).

There are many types of studies and data that are used to support vegetation management, ranging from literature searches, inventories, and experimentally derived data to long-term surveillance monitoring (Nichols and Williams 2006). The Heartland Inventory and Monitoring Network (Heartland Network) was formed in 1994 and featured vegetation monitoring as one of its core projects (Middlemis-Brown 2016). Long-term vegetation monitoring is conducted on a rotating basis, but without respect to management activities or ecological disturbances. Alternatively, fire focused monitoring prescribed by the NPS (USDI 2003) recommends conducting monitoring with respect to time since fire. The Fire Monitoring Handbook prescribes vegetation monitoring every 1, 2, and 5 years post-burn (USDI 2003). This is an ideal way to monitor fire prone systems so that fire treatments can be clearly attributed to effects on vegetation, particularly when mean fire return intervals are greater than five years.

Grasslands of the central U.S. and eastern Great Plains rely on frequent prescribed fires to restore and maintain them, but historical fire return intervals are difficult to document. In addition to spatial remote sensing techniques, fire historians use tree-ring analysis of tree fire scars from adjacent woodland areas to infer fire occurrence in surrounding grasslands (Stambaugh et al. 2009; Guyette et al. 2011). Using these techniques Guyette and others (2011) found that historical fire return intervals varied across national parks in the Great Plains. Fire is frequent in the southern Great Plains (1–3 years) with longer intervals in the northern Great Plains

(3–5 years; Bragg 1995; Anderson 2006; Guyette et al. 2012). Fire history in national parks requires more local precision, especially where sites are heavily influenced by human populations (Guyette et al. 2011).

In tallgrass prairie, recent fire events become obscured after 1–2 growing seasons, making remotely sensed fire history assessments challenging. Remote sensing techniques for mapping fires include comparing pre-burn and post-burn images for changes in greenness values (through indexes like NDVI (normalized difference vegetation index), normalized burn ratio (NBR), or using the available sensors from a single scene to detect the black burn scar (EROS and RSAC 2016). Fire in tallgrass prairie stimulates vegetation growth and the black ash quickly transitions into dense green vegetation. Once the prairie cycles through both a growing season and dormant season, the signals can be hard to detect. This contrasts with woodlands where tree mortality may be delayed over the course of a few years post-burn.

Programmatically, long-term monitoring based on fire history is also impractical in frequently burned tallgrass prairie. Implementing vegetation monitoring based on fire occurrence as prescribed by the Fire Monitoring Handbook (USDI NPS 2003) would result in all monitoring sites in parks of this ecosystem being monitored each year. The Heartland Network is responsible for vegetation monitoring at 11 parks scattered across the central U.S. The post-burn revisit schedule prescribed by the Fire Monitoring Handbook was simply not practical as all grassland monitoring sites in the network would need to be revisited nearly annually. Instead, we developed a monitoring site-based spatial fire history so that fire metrics could be used to quantitatively understand patterns in the vegetation monitoring data and support management actions, particularly fire management.

Understanding fire occurrence at the monitoring site scale required developing spatial data reflecting each park's known recent fire history, sometimes called a fire atlas. A number of sources were consulted in the process and cross-referencing was critical. This step was followed by developing a tool to calculate burned status for each site and year combination.

Fire history records for areas under focused management often languish in paper files and disparate digital formats such as pdf maps and shape files. Without a concerted effort to collate and organize this information, the knowledge of land management history can be lost, or left as oral history. In describing our process for developing a fire history geodatabase, we aim to document our

process and solutions as well as encourage managers and fire ecologists to invest in developing their fire history data into usable archives. In this study, we describe (1) the development of the Heartland fire occurrence geodatabase (HFOG) and (2) metrics derived from it. We provide examples of analyses that utilize these data including a network scale understanding of fire history.

Methods

The fire occurrence data and products discussed here were developed for a suite of parks within the Heartland Network where focused fire ecology monitoring was ongoing: Effigy Mounds National Monument (NM), George Washington Carver NM, Herbert Hoover National Historic Site (NHS), Homestead National Historical Park (NHP), Pipestone NM, Tallgrass Prairie National Preserve (NPRES), and Wilson's Creek National Battlefield (NB). These parks span five states across the central US and all of them include tallgrass prairie community types as reconstructions, remnants, or both.

Geodatabase development: sources

Fire occurrence information was acquired from multiple sources over time. First, Heartland Network staff maintained a spreadsheet of observations of long-term monitoring sites that had recently burned prior to monitoring events. This record was initiated in 1996 when network ecologists were visiting parks frequently (twice each year for two consecutive years followed by a three-year lieu period).

Nationally, fire reporting has evolved from the individual fire report form (DI-1202) developed in 1982 to more centralized versions of databases. This report includes details of each fire, including the location, vegetation types, fire size, fire behavior, and crew size. The Wildland Fire Management Information database (WFMI) was initially available to input and archive the DI-1202 reports electronically on an interagency scale ([Wildland Fire Management Information, https://wfmi.nifc.gov/cgi/WfmiHome.cgi](https://wfmi.nifc.gov/cgi/WfmiHome.cgi), DOI 2011). In the 1990s, WFMI included additional modules for lightning detection, weather, and fire reporting. However, WFMI has been replaced by [InFORM as the official fire reporting system of the Department of the Interior \(https://in-form-nifc.hub.arcgis.com/\)](https://in-form-nifc.hub.arcgis.com/). InFORM is spatially explicit and newly implemented since 2020.

An additional database, [NFPORS \(National Fire Plan operations and reporting system, http://www.nfpors.gov/\)](http://www.nfpors.gov/), was installed in 2003 to collect information related to the national fire plan for the Department of the Interior (DOI 2011). Fuels reduction activities,

such as prescribed fire and fuels treatments, were subsequently added to this database. NFPORS tracked planned treatments and related budgetary needs as well as project completion. It served as a complement to WFMI, which focused on fire occurrence. The NPS later began curating fire occurrence data in a national fire occurrence geodatabase. Although the earlier versions of the reporting and database systems helped to standardize fire reporting, the data were prone to spatial and input errors (e.g., incorrect coordinates for ignition points or missing dates or burn unit names).

Sources for our Heartland Network fire occurrence geodatabase (HFOG) included a suite of data types (Table 1). WFMI data occurred as points and later as polygons while NFPORS data were not spatial. To compile recent fire histories for our parks, we reviewed the WFMI points, fire reports (DI-1202 forms), NFPORS data, and hard copy hand drawn maps and notes residing in park archives. Additional documentation included fire management plans (FMP) which described burn unit perimeters (either in map or narrative form) and sometimes included a fire history by burn unit. Heartland Network's annotated spreadsheet was consulted and available spatial data from NPS data stores were included. Personal communications from managers were also used to clarify discrepancies.

Geodatabase development: assembly

Heartland Network began bringing the various data sources together into a spatial geodatabase in the early 2000s (Table 1). Spatial data procured from all known, available store houses including the NPS datastore were consulted. The variety of sources meant that not all information related to a given fire agreed or was complete and attributes were not necessarily parallel.

Data not already in a geographic information system (GIS) format (like hard copy maps) were used to create polygon features by heads-up digitizing based on imagery, management units, staff knowledge and reports. All fire GIS layers were then converted to the feature class format and imported into a geodatabase. (Personal communication, J. Haack-Gaynor.)

Table 1. List of sources for fire occurrence information for parks in the Heartland Inventory and Monitoring Network.

Data Sources Compiled to Build the Heartland Fire Occurrence Geodatabase	Years Available	Confidence	Resolution
*Data points from the Wildland Fire Management Information (WFMI) system	~1990–2020	High	Point
Databased records from the National Fire Plan operations and reporting system (NFPORS)	~2007–present	High	Burn unit or park scale
*GPS collected fire perimeters (HTLN Staff)	2009–2020	High	Submeter
Spatial data from park files	Prior to 2007	Moderate	Variable
Park management documents (plans, reports, and unpublished notes or lists)	As available from parks	Moderate	Non-spatial data
Spatial data from the NPS Data Store	Prior to 2007	Moderate	Park or burn unit scale
Imagery from available digital clearinghouses and libraries	Prior to 2007	Moderate	Variable
HTLN spreadsheet of fires by monitoring site	1996–2008	High	Non-spatial (0.1 ha)

*Served as a baseline authority where available.

Geodatabase development: verification and reconciliation

We worked to consult and verify fire perimeters using a variety of sources for fires prior to 2009. Once Heartland Network began to collect fire perimeters in the field with a global navigation satellite system (GNSS) unit (2009), the field mapped data became the authority.

To verify records and correct erroneous data, we employed a technician to improve the geodatabase. Starting with the points and polygons from the national dataset (WFMI), we used other sources to verify the occurrence and locations of fires (Table 1). If points were the only digital spatial data available for a fire, a burn unit was drawn based on attributes of the point and known burn unit designations at the time of the fire.

When the WFMI points/polygons agreed with other sources, no editing was required. In the case that available sources of information for a fire disagreed, we required at least two sources to corroborate the location of the fire before editing existing data (primarily WFMI data). If more than one source was not available to verify the location of a burn, we defaulted to the WFMI data as the authority. Heartland Network staff observations documented in spreadsheet format were among the critical sources consulted for verification.

Because we consulted several available sources for each fire perimeter, we believe that the HFPG was accurate and complete. Despite opportunities for improvement that technology will provide in the future, we created the best possible record of fire history for the parks. Omissions included specific event identification numbers for each fire perimeter, a consistent suite of attributes for each fire, and unburned areas within a burn unit. These identification numbers tie a burn event polygon to the national fire occurrence dataset. Attributes also varied from fire to fire or park to park depending on the state of the source data; for example, dates or fire names may or may not have been included.

Often, the spatial data simply consisted of burn unit boundaries drawn as the fire perimeter without further detail inside the perimeter. This was common practice for spatial records of fire perimeters especially for smaller burn units. Unburned areas within a burn unit were also not included in these perimeters, so directly applying fire history to the vegetation monitoring sites required assuming complete burns.

To further improve fire occurrence data for the network, we began collecting the fire perimeters using GNSS devices in the field (Leis et al. 2011). Fires at our suite of parks were relatively small and remote sensing wasn't initially supported, so we collected the fire perimeters in the field beginning

in 2009. We improved on the fire perimeters by collecting unburned inclusions in a burn unit within a set of thresholds and provided more detailed perimeters. By doing so, we increased our confidence in whether monitoring sites had been burned.

Sources of uncertainty

Spatial uncertainty

Over the lifespan of the HFOG, spatial resolution of background imagery increased and GNSS technology and GIS software and products improved. These changes increased uncertainty in older fire perimeters at small scales, limiting understanding and inference to larger scales such as burn unit or park scales. For one park, Tallgrass Prairie Nation Preserve, we only have explicit records for fire from 1998–present, although we know anecdotally that fires burned annually for many years prior to 1998.

Temporal uncertainty

Although Heartland Network recognized the importance of archiving fire occurrence data for network parks, specific analyses relating fire history to vegetation data were rarely done (see James and DeBacker 2007, Leis and Morrison 2018, Williams et al. 2007, Leis and James 2008 for examples). Given the lurking deficiencies of the early records in the HFOG we decided to limit metric calculation to a less spatially explicit form, such as at the park scale, for fires from 1950–1994. Finer scaled calculation of fire occurrence (burn unit or monitoring site scale) became possible with the HFOG (1995–present).

Confidence in the spatial data increased in more recent years as the Heartland Network staff had field observations to corroborate more records (1995–present) in spreadsheet format and GNSS field data. Communication between parks and the Heartland Network related to fire activity and goals also increased in recent years allowing for increased data collection and verification. Even so, sites were not necessarily visited immediately post-burn for verification of fire treatments. For this time period, we needed an analysis tool to calculate whether vegetation sites could functionally be considered burned from the HFOG. This analysis tool would allow us to calculate a fire history for each monitoring site.

Product development

To create a monitoring site-based fire history analysis tool, we developed an analysis geodatabase based on the HFOG including the years 1995–present. The analysis tool calculated a 30-m circular buffer from the center of each 0.1-ha monitoring site. The area of the buffered monitoring site intersecting a burned polygon was calculated for each fire event. The data from the analysis tool was exported and an arbitrary threshold was applied. At least 30% of the buffered area containing the monitoring site must have been burned to code the site as burned for further analysis. From these data, metrics such as time since fire and fire return intervals were calculated for a given site. The fire occurrence metrics were then summarized or included as explanatory variables in vegetation analyses (for examples see Leis and Morrison 2020, Leis and Short 2019, and Leis and Short 2021).

Results

The 7-park fire atlas described here included fires from 1950–2019 (70 years). Wildfires (unplanned fires) were rare in the fire atlas but occurred occasionally. Only 13 of the fires recorded in the HFOG were known to have been unplanned ignitions (Table 2).

The number of parks using fire each year peaked from 1999–2002 (Figure 1). There were two years in the record where no parks had a fire: 1979 and 2013. Prior to the NPS policy encouraging prescribed fire around 1988, we have records of only a few of the parks burning. However, we know that Tallgrass

Prairie National Preserve has a long history of fire, but that information wasn't available in a spatially explicit way prior to 1998. As agency policy facilitated the increased capacity for the fire program, more parks were burned. All parks had fires in the years 1999–2002. There was a reduction in the occurrence of fire in the seven parks after 2002. From 1950–present (for years where data were available), an average of 56.0% of the seven parks had a fire in a given year. The average number of parks burning in a year from 1988 (start of policy implementation) to present was 73.7%.

Table 2. Description of fires contained in the 7-park fire atlas. Record length is calculated from year of first recorded fire in geodatabase to present. Years were counted if a fire occurred somewhere on the park, both planned and unplanned fires were considered.

Park	# Years Fire Occurred on Park	Geodatabase Record (yrs)	Percent of Years in Record with Fires
Homestead National Historical Park	34	50	68
Pipestone National Monument	44	49	89.8
Tallgrass Prairie National Preserve	21	22	95.5
Effigy Mounds National Monument	22	60	36.7
George Washington Carver National Monument	32	38	84.2
Herbert Hoover National Historic Site	17	28	60.7
Wilson's Creek National Battlefield	29	32	90.6
Mean	29.3	39.9	78.1

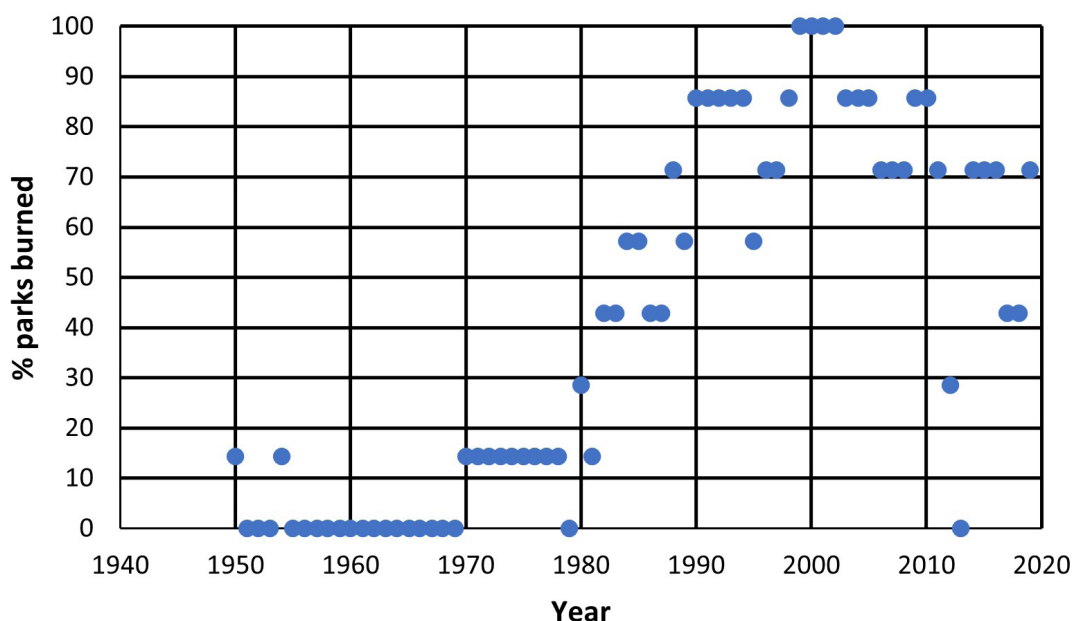


Figure 1. Proportion of seven grassland parks in the Heartland Inventory and Monitoring Network where local records indicated that a fire occurred for 1950–2019.

Fire Return Interval Status: Pipestone National Monument

Target fire return interval: **3–5** years.¹
Fire history calculated: **November 2020**.



Recent Fire History

Units	Years Since Last	Last Burn Date
1	4.0	22-Oct-16
2	11.5	11-May-09
3	1.5	15-May-19
4	4.5	19-May-16
4a	3.0	29-Nov-17

- Units meet target return interval (0–3 years):
- Units near return interval target (3–5 years):
- Units beyond return interval target (>5 years)

¹Source: FMP Environmental Assessment. 2004.

Figure 2. Map of fire return interval by burn unit at Pipestone National Monument was developed using the Heartland Inventory and Monitoring Network fire occurrence geodatabase (HFOG). The product was useful for planning and discussions related to fire ecology and park management.

These data were also used to create maps of recent fire history for planning purposes. Figure 2 provides an example.

Using the analysis geodatabase derived from the HFOG, we were able to calculate finer scale fire occurrence for monitoring sites rather than the larger scale summaries for parks previously described.

Doing so gave us the ability to better relate fire occurrence with vegetation trends. Examples can be found in published monitoring reports (Figures 3, 4, and 5). Recent reports include fire history for George Washington Carver NM and Wilson’s Creek NB (Leis and Short 2021; Leis 2022).

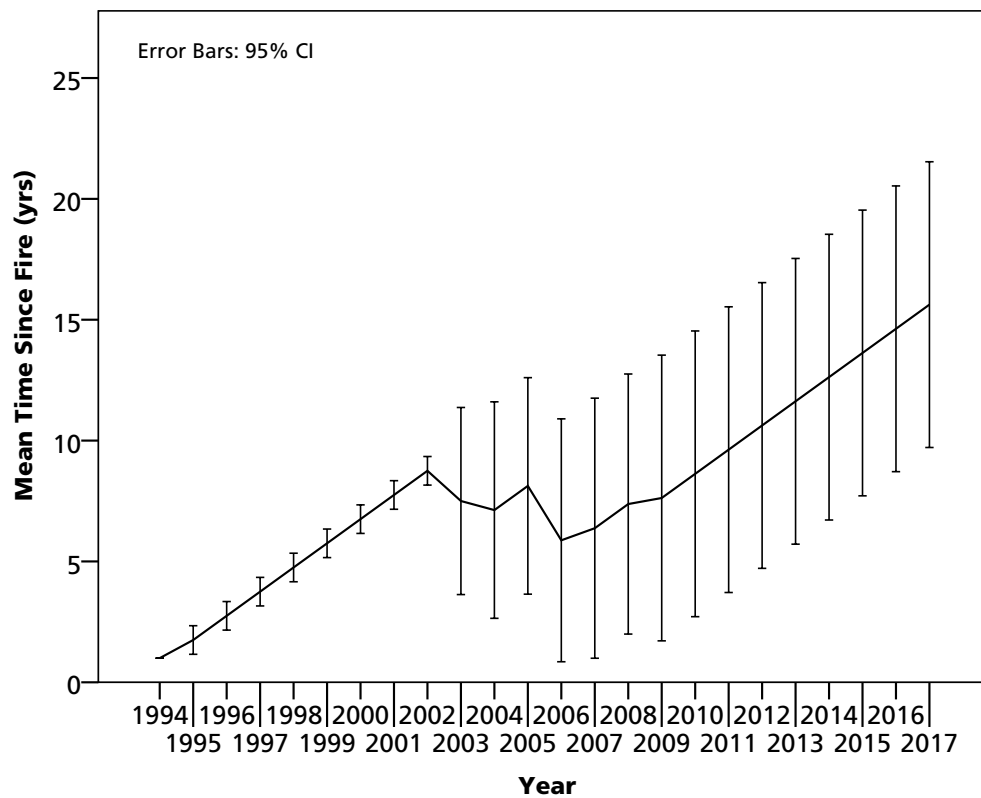


Figure 3. Fire occurrence at vegetation monitoring sites at Effigy Mounds National Monument, Harpers Ferry, Iowa. Fire became less frequent and more heterogeneous through time (N = 8; Leis 2020).

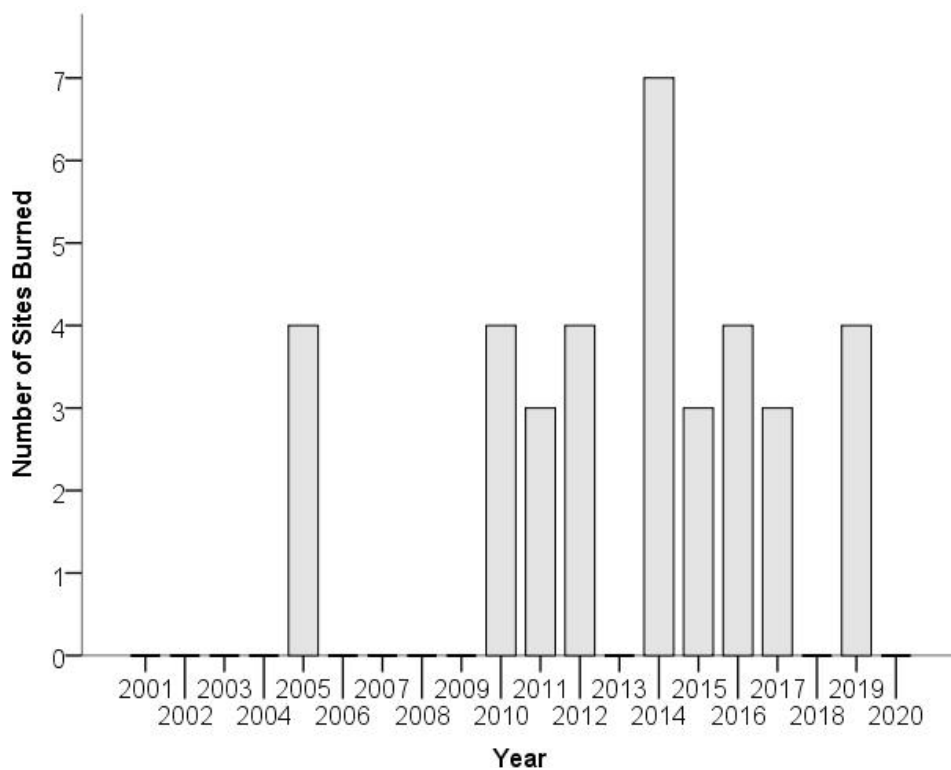


Figure 4. The number of sites burned out of seven during the period 2001–2020 at George Washington Carver National Monument, Diamond, Missouri (Leis and Short 2021).

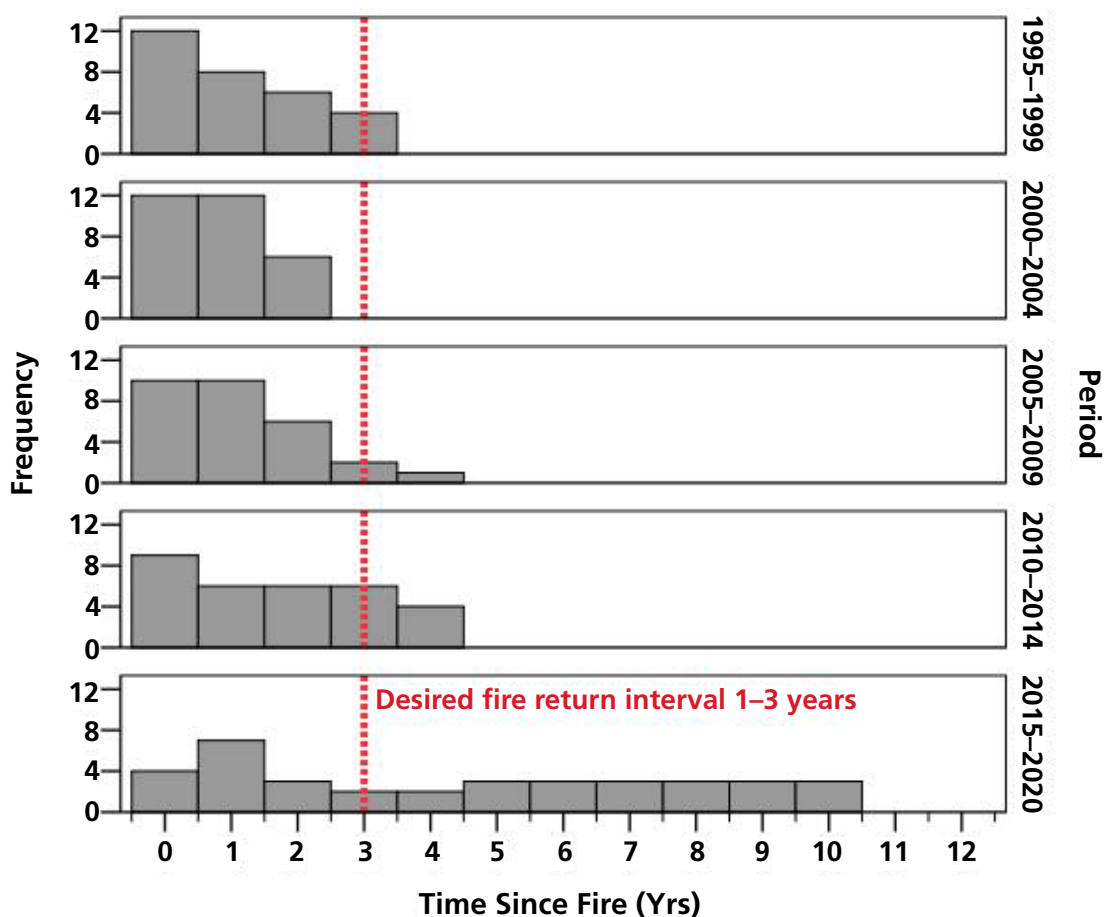


Figure 5. Time since fire frequency for six restored tallgrass prairie monitoring sites at Wilson's Creek National Battlefield, Republic, Missouri (Leis 2022). Each site was assigned a time since fire value for each year from 1995–2020 and results are displayed in five-year intervals. The red dotted line indicates the maximum desired fire return interval for these sites.

Future research projects using the data and analysis tools described here may include studying the site level trends in fire occurrence within and across the seven parks and how that relates to community level vegetation trends. If funding support becomes available, we also wish to work to create more consistent attribute tables for older fire event polygons in the geodatabase.

We will continue to use the data to inform management decisions where opportunities arise. Anticipated examples include annual management work planning; revisions to implementation plans, such as fire and vegetation management plans; and expanding implications for ecological trend monitoring reports for the network.

Discussion

The Heartland Inventory and Monitoring Network assembled a fire occurrence geodatabase for seven network parks. Although we drew upon several available sources of data, we were able to create a comprehensive record of fires within these national parks. Because of some limitations of the earlier data, we determined which spatial scale of inference was appropriate for two temporal scales of data. Older inferences were limited to the park scale while newer inferences were appropriate at the monitoring site scale. This data set and decision process provided the network with information to relate to vegetation and wildlife data and for natural resource and fire management planning.

Analysis of fire atlases (time series of fire perimeter data) can facilitate learning about changes in landscape patterns for both fire occurrence and fire effects on vegetation (Rollins et al. 2001; Morgan et al. 2014). Case studies by Rollins and others (2001), as well as Morgan and others (2014), acknowledge that accuracy of perimeters may not be fully known and that the data are imperfect but have great utility and provide meaningful insights. Much like our study, the fire atlas described by Morgan and others was developed using multiple sources of data including hand drawn maps and GPS receivers of differing accuracy (2014).

Matching the scale of fire occurrence with the scale at which effects are measured can be challenging. Fires are often incomplete, leaving unburned inclusions that may include monitoring locations. Without detailed mapping of the fire, analysts may assume that all sites in a burn unit were burned leaving fire effects on vegetation obscured. Although studies of fire atlases often describe large-scale woodland fires, it is rare to see fire occurrence described spatially for grassland ecosystems (Mohler and Goodin 2012; Donovan et al. 2017; Scholtz et al. 2018). Although small grasslands often burn completely, many include moist areas or woody plant encroachment that limit fire movement or reduce severity. Understanding these dynamics through a spatial geodatabase can be helpful for understanding plant community dynamics, even in grasslands (Scholtz et al. 2018).

While fire atlases like the HFOG have utility for retrospective analysis, they also contribute to anticipating future changes to vegetation as the result of changes in fire occurrence through time (Collins et al. 2007; Heisler et al. 2003; Polley et al. 2013). In our grassland parks, we may anticipate signals of woody plant encroachment or declines in plant diversity with reductions in the application of fire.

The HFOG is a valuable resource for ecological monitoring work and collaborating with land managers and fire operations staff. Creation of the HFOG has facilitated better understanding of fire occurrence for network staff and for parks. Scientists and managers are able to reference fires through time to better understand vegetation data and to develop management actions, such as scheduling fires or invasive plant treatments. Additionally, we were able to create communication products at different scales to facilitate understanding and collaboration using these data. Products ranged from monitoring reports to fire history maps and insights used for creation of fire management goals and objectives.

Changes in spatial resolution over time increase our confidence in newer fire perimeter data, but complicate understanding of older data at lower resolutions. Applying the analysis geodatabase increased confidence in calculations of fire occurrence at monitoring site scale (0.1 ha). There are always improvements that can be made such as creating consistent attributes for past data or remapping fires using new remote sensing tools, but those investments require a great deal of personnel time and funding and carry their own levels of omission and commission errors.

The Heartland Network HFOG was developed using multiple data sources. Although the database contains imperfections, it helps us understand and communicate vegetation trends at the park scale, and the database information is useful for management planning. Future analyses may include regional scale fire occurrence within the parks.

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1201 Oak Ridge Drive, Suite 150
Fort Collins, Colorado 80525