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Matching Long-Term Fire Effects Research to Pressing Questions Facing Tallgrass Prairie Managers across the Upper Midwest

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ABSTRACT The goal for this paper is to explore how a network of coordinated prescribed fire experiments could be developed and applied to tallgrass prairie management. In a 2011 survey conducted by the Tallgrass Prairie and Oak Savanna Fire Science Consortium in their region, 61% of 207 land managers indicated that their greatest need with respect to fire regimes was information on the outcome of variations in fire frequency and season, with information on these variables ranging from limited to completely lacking. Need for this kind of information was echoed during a breakout discussion session at the 2016 North American Prairie Conference where researchers and land managers shared their opinions on how the potential costs and benefits of developing a research network with experimental treatments could be relevant to management needs. The discussion was encouraging, although researchers noted funding as an important barrier. An example of the informative nature of long-term fire studies is ongoing at the University of Nebraska at Omaha where an experiment established in 1978 has shown strong differences among vegetation and soils in plots burned in different seasons and with different frequencies. A network of sites replicating this type of experiment across the region would inform land management decisions at a broad array of sites that are represented by a variety of soils, weather, climate, and plant species, including invasive plants. All these variables have been hypothesized to be important predictors of fire effects at some location, but the relative importance of different variables across the region has not been quantified through monitoring or research. In this paper, we outline potential steps for a sustained effort to investigate the benefits and risks of engaging in and funding a regional fire research network.

KEY WORDS fire ecology, fire effects, Glacier Creek Preserve, land management, long-term, prescribed fire, research network, tallgrass prairie

INTRODUCTION

In general, there is a need for more research on the effects of fire for conserving biodiversity (for a global review, see Driscoll et al. 2010). This need was noted more locally when, in a 2011 Tallgrass Prairie and Oak Savanna Fire Science Consortium (TPOS) startup survey, land managers across the central and northern tallgrass prairie (Figure 1) were asked to indicate their greatest needs for information relative to using prescribed fire. Of the 207 practitioners responding to this survey, 61% indicated the need for more information about fire regimes, in particular the effects of fire frequency and season. For example, how does fire frequency and season of burning affect outcomes in planted or remnant prairies across the tallgrass prairie region? The need for information on fire frequency and season of burn was reiterated during the 2016 North American Prairie Conference plenary presentation by Rich Henderson, Wisconsin Department of Natural Resources ecologist. Henderson stated that fire research is needed that 1) addresses the problems of extrapolating results from one part of the region to another and 2) assesses important variables over the long term.

This paper discusses the temporal and spatial aspects of this research. First, we describe potential objectives of a long-term study network; then we offer a case study via the senior author's long-term research at the Glacier Creek Preserve at the University of Nebraska at Omaha. We conclude by reviewing discussions at the North American Prairie Conference breakout session and outline next steps toward developing a network.

THE IMPORTANCE OF LONG-TERM RESEARCH

The value of long-term ecological research (defined here generally as research lasting over decades) was recognized as early as the 1980s (e.g., see Franklin 1989). Organizations focusing on long-term studies presently include the National Science Foundation–funded US Long-Term Ecological Research (LTER) Program (https://lternet.edu/) established in 1980 in the United States; International LTER network (https://www.ilternet.edu/) established in 1993; and the LTER-Europe (http://www.lter-europe.net/) established in 2007 (e.g., see Callahan 1984, Gosz 1996, Mirtl 2010 for more details on these programs). These formal LTER

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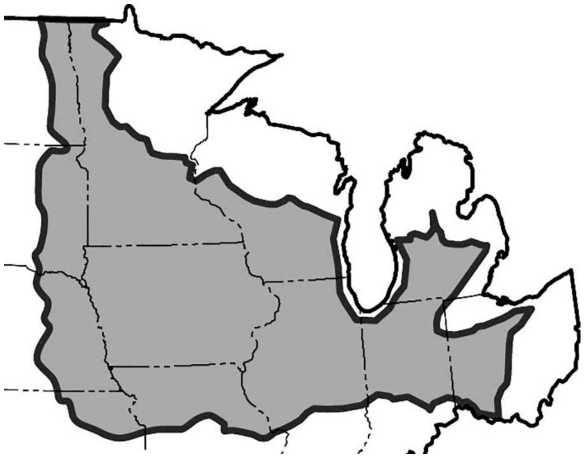

Figure 1. The Tallgrass Prairie and Oak Savanna Fire Science Consortium (TPOS) boundaries include parts of 12 states in the United States, including northern and central tallgrass prairie ecoregions. TPOS is funded by the US federal Joint Fire Science Program, and is one of 15 fire science exchanges across the United States that serve to increase the awareness, understanding, and adoption of fire science (http://www.firescience.gov/JFSP_exchanges.cfm).

programs were founded because long-term and broad-scale research was recognized as being necessary to more fully understand environmental phenomena with the intent being to inform decision making in a broad range of key ecosystems. Reinforcing the value of long-term study, Hughes et al. (2017) shows the use of long-term studies in informing policy is greater, and the studies more valued, than shorter term studies reported in the ecological literature. However, these authors note that presently, just when there is an increasing need for understanding how species and ecosystems respond to a changing global climate, there is a concomitant decline in the relative investment in long-term ecological and environmental studies.

Value of a Network of Long-Term Study Sites for Fire Ecology and Land Management

To increase our understanding of how to manage tallgrass prairie ecosystems, the authors, in association with TPOS, hope to initiate interest in discussions that will result in development of a network of long-term research and education sites across the region. This approach focuses on long-term study consistent with the broad perspective for which national programs, such as the LTER, were established but also acknowledges the obvious—that within any single ecosystem, particularly those covering large landscapes, effects of management (e.g., fire, mowing, grazing, etc.) will vary both in time and location. Only through research conducted over many years and across an entire ecosystem will the effects of varied management be clearly understood for any particular location. At the outset, though, it is essential to understand that it is highly unlikely that there is a "silver bullet" for managing all parts of any broadly occurring ecosystem.

The approach we propose is intended to expand our understanding of the effect of variations in fire frequency and fire season by creating a network of sites that use standard data collection protocols coupled with capacity to collect, store, and analyze shared data. An example of such a network is the Nutrient Network (nutnet.org), which was established to address how human impacts on ecosystems are changing global nutrient budgets. This research network arose to deal with issues of "context and contingency" that had led to a great deal of statistical noise from isolated experiments exploring the effect of fossil fuel combustion and agricultural fertilization on ecosystem function (for an overview, see Borer et al. 2014a). Similarly, creating a long-term prescribed fire research network across the tallgrass prairie region would be a significant step toward addressing land management needs.

Replicating experimental treatments and sampling at sites across the region would clarify how different site attributes determine first- and second-order fire effects. First-order fire effects occur during and immediately after a fire, such as fuel consumption and direct mortality of organisms. Second-order fire effects, sometimes referred to as "indirect" fire effects, occur after a certain amount of time has passed, and include changes in soil temperature, moisture, and inorganic nutrients as well as changes in habitat structure as vegetation responds to postfire conditions.

Variability in soils, weather, climate, and plant species (including invasive plants) are all hypothesized to be important drivers of fire effects, but the relative importance of different variables across the region have not been quantified. Land managers report that it is difficult to determine how well results from a single research site might apply to their management site, particularly when they know by experience that applying similar management treatments to different sites can lead to different outcomes. Analysis of data from multiple sites may yield information about the strength of site attributes and other factors that land managers can use to interpret how a specific prescribed fire treatment might affect their sites.

Benefits of Networking for Field Stations and Researchers

Research projects at field stations across the tallgrass prairie region have the potential to benefit from joining a research network. For example, the University of Wisconsin–Platteville (UW-Platteville) has approximately 81 ha (200 acres) of natural areas, which serve as a living laboratory and general greenspace. Some isolated research has been conducted in these areas, as have sporadic management and restoration efforts, but the degree to which this information can be applied elsewhere has not been explored. The work at this site, therefore, could benefit by joining a research network. Among many benefits, a collaborative network could:

Involve more researchers.—A network could provide an incentive for more researchers across disciplines to be involved—for example, at UW-Platteville, researchers engaged could include soil scientists, mammologists, herpetologists, botanists, restoration ecologists, and biogeographers, to name a few.

Draw upon a broader range of specialists.—A network can allow researchers at an institution to work with a broader network of specialists enabling exchange of information on such considerations as research methodology.

Increase student interest.—Student interest could increase with a collaborative network, since their research would be part of something more significant than a short-term study at a single university; and

Encourage administrative support.—For organizations, such as universities, administrators would likely have greater buy-in to support ongoing research that is part of a collaborative network, rather than stand-alone research, since belonging to a network would increase exposure for their organization across a broader region.

Benefits of Long-Term Studies

Long-term studies can be beneficial in many ways that can better inform land management decisions. The following are some of such benefits:

Incorporates temporal climatic variability.—Weather conditions vary over time and across a region. Drought years may follow wet years with each set of conditions having the potential to result in different responses to the same type of management. Since no short-term climatic condition is likely to alter species composition, at least not where tallgrass prairie prevails (Bragg, personal observation), the most important effect to a land manager is the net effect that incorporates effects of variable climatic conditions over the years, which can only reasonably be assessed with long-term studies.

Incorporates delayed community response.—Over time, the trajectory of a plant community (i.e., community momentum) is affected by numerous factors, including the longevity of individual species, reproductive success of populations, and conditions of the physical environment (e.g., soil structure, pH, soil organic matter, etc.). A short-term study may not provide adequate time for the community to change its course to show the true effect of management. For example, 20 y of annual burning of long-term research plots at the University of Nebraska at Omaha's (UNO's) Glacier Creek Preserve resulted in changes in soil structure (i.e., the arrangement of soil separates into units called soil aggregates) as reflected in differences in infiltration rates (Schacht et al. 1996). This soil response may, in part, account for the differences in plant species composition. It seems unlikely that changes in soil characteristics, such as soil structure or soil texture (i.e., soil particle size), and any associated change in plant species composition, would result from only a few years of burning.

The role of serendipity.—In addition to original research questions, serendipitous results—that is, results unrelated to the original research questions—are becoming more common (e.g., Doak et al. 2008, Sagarin and Pauchard 2010). Given the limited, although growing, number of long-term studies, unexpected results or insights may develop from them over time.

Benefits of Networked Long-Term Studies

Advantages of linking several long-term study sites within a region include the following.

A network would increase the scientific rigor of research by allowing true replication of field study sites (e.g., Hurlbert 1984).

A network incorporates climate variation within a region. Even within an ecoregion, temperature, precipitation, and other climatic characteristics vary, with any one of these variables having the possibility of affecting either vegetation supported or the response of that vegetation to management. Providing long-term data from multiple locations across the region will allow land managers to compare several locations to their particular site rather than extrapolating from one distant site.

A network would incorporate variability in biodiversity (community composition, species ranges, intraspecies variability, etc.), soils, and dominant land uses across the region. These potential drivers of land management outcomes may be highly correlated to climatic variability across the region, but may also provide data that will allow researchers to determine the relative contribution of climate and other variables to land management outcomes (for example, see Borer et al. 2014b).

Because long-term research studies have time and space limitations, it seems likely that only a few such studies will be established or maintained. Consequently, these few studies need to be strongly networked to insure that a maximum number of sites across any region are available to exchange information.

Collaboration and coordination among ecological researchers, land managers, and others within an ecoregion will allow for standardizing data collection to facilitate comparability among sites, and to determine the degree to which information at one location can be extrapolated to others within the ecoregion.

Networks provide a platform for considering additional research questions that might not be obtained from a single site.

A network has the potential to establish a repository for data for future reference.

Establishing a network may encourage monitoring among land managers. Monitoring, if coordinated with a research network, could inform land managers if their management decisions are accomplishing desired objectives while also providing another source of data on the effects of land management.

Each individual site within a network may have different objectives and goals, but some common denominators among research protocols could allow for sufficient data to make regional comparisons of fire effects. A collaborative network of sites with standardized measurement of ecosystem characteristics (e.g., fuels, fire weather, fire behavior, above- and belowground primary production, biotic diversity, effects on native and nonnative invasive plant species, soil and soil biota, etc.), and their response to various intensities, frequencies, and timing of disturbances (such as fire, mowing, haying, and grazing) can better inform land management decisions.

Considering the Scale of Long-Term Study

The scale of long-term study can vary widely but basically may be divided into 2 different levels: large scale (e.g., preserve- or site-wide level) or small scale (e.g., experimental units). At both scales, statistical analysis of biotic and abiotic variables typically requires collecting data via subsamples such as quadrats or transects. Monitoring methods, used to determine if management objectives have been met or to gauge long-term trends, sometimes use less-intensive sampling methods such as relevé, plots, or meandering walks.

Large-scale (site-level) study.—Any large tract of land has the potential to inform management. Perhaps the most important advantage is that results of management of a large area are likely better to reflect the effect of actual implementation of a particular management regime. However, to provide such information at the level of a ranch, pasture, or preserve, samples need to be collected that are amenable to interpretation and statistical analysis. Several studies in the tallgrass prairie region have used resampling of large natural areas to examine the relative effects of fire return intervals and other variables (Milbauer and Leach 2007, Bowles and Jones 2013, Alstad and Damschen 2016).

Small-scale (experimental-unit) study.—Experimental units are established to assess the effects of different treatments (i.e., types of management). Within each experimental unit, multiple subsamples (quadrats or transects) are needed to reflect spatial variation. Principal advantages of subdividing one site into experimental units rather than making assessments at the site level include (1) the ability to assess a greater number of types of management within a smaller area than can be practically accommodated using multiple large areas, (2) the ability to more closely control treatment conditions, and (3) the ability to include multiple replicates of each treatment, not multiple samples from a single treatment, for statistical analysis. In addition, Hulbert (1984) noted the potential pitfalls of pseudoreplication within the same site.

Design Considerations for Long-Term Studies

Long-term studies may originate from several sources. In some instances, they result from simply continuing a short-term research project over a long period of time. In other instances, though, the initial intent can actually be the development of a long-term study as explained in the case study discussed below. The latter is preferred since it allows for more complete planning and collection of pretreatment data. Whether planned as a long-term study or evolving from a short-term study, a study become increasingly more valuable as it is continued over time. There are numerous considerations when initiating a long-term study, many of which are also relevant to short-term studies and to plot-level or large-scale research. The list below was developed mostly from the lead author's personal experiences. While perhaps incomplete, these points provide a starting point for those interested in initiating or continuing long-term research.

Objective, objective, objective.—The first step is always the development of a research or management objective. That objective will determine whether a long-term study will provide the kind of information you are seeking or whether some other approach is more appropriate.

Slow study.—At the outset, it is essential to understand that long-term studies are not designed to provide quick results. For example, it takes 12 y to assess the effect of just 3 fire treatments on experimental units in a quadrennial burn treatment. Patience is an initial requirement for long-term study, although interim results can provide useful information on tracking community dynamics that occur in response to successive treatments.

Site suitability.—What is the potential longevity of the site itself? Is the site (e.g., preserve, etc.) expected to be maintained long enough to warrant setting up a long-term study? Is there institutional support for the site (and the study)? Because meaningful results are likely to take years to bear fruit, individuals in administrative positions should be aware of the value of continuing to support the site on which long-term study is proposed.

Study longevity.—To ensure continuation over long periods of time, a long-term study needs to be an integral part of a preserve's design and management so that it continues after initial interest by an investigator ends. This information is not provided to discourage shorter-term research plot studies but only to caution that long-term studies must be seen as ones likely to exceed the educational life span of any individual investigator.

Networking or independent research.—Developing a new, long-term study within a network of long-term research sites that collect similar data on similar types of management is proposed here as an efficient way to assess how well results at any one site can be extrapolated across a larger region. A network also takes into account statistical concerns about replication (multiple sites) versus pseudo-replication (i.e., multiple plots of a single treatment at one site). That said, the temporal nature of long-term studies, even without replication across multiple sites, does give results useful for land managers as well as providing data that can be tested statistically. For example, long-term research at one site can provide insight into the magnitude of slow changes that are difficult to perceive, such as changes in precipitation or expansion of invasive species. However, this information would increase in value for a region if collected across a cooperating network of sites.

Study design.—Carefully think through the experimental design before initiating a study, then resist changing the design without a good reason, at least not after the first year or so.

Keep in mind the logistics of sampling and treatment. How much annual sampling can practically be accomplished—are there too many plots to sample in any one year? Does that make a difference? How many plots are necessary to accomplish your research objective? One of the disadvantages of long-term studies is that the data are cumulative. Each time you add a long-term study site to your sampling commitment, you increase the time needed each year to collect data and decrease the time available for other endeavors. The time commitment needs to be carefully considered, particularly with long-term research efforts. Applying statistical modeling techniques, such as power analysis, to inform sampling intensity is advised as a necessary step in development of a long-term research network.

Carefully plan a treatment design that can actually be applied. Are you proposing a long-term burn study in an area where surrounding development or other trends point toward restrictions on burning? When varying the season of annual burn treatments, will there be sufficient fuel for the next treatment? To burn frequently, will there be sufficient fuel or fuel continuity to carry a fire between scheduled treatments? For example, with annual summer (growing-season) burn treatments, will there be sufficient plant growth and curing to provide fuel to carry a fire during the next growing season?

Consider site replication and pseudoreplication. Are you able to consider true replication? If not, the temporal component of long-term studies, even without replication, provides data amenable to statistical analysis, for example a repeated measures analysis of variance (ANOVA). Networking, however, adds the possibility of establishing replicate sites.

For experimental units established within a larger area, consider the logistics of size, shape, and location of plots and how their location may affect management of the larger area. For example, will the experiment require fencing from adjacent grazing land or protection from large-scale fire treatments? If so, how might the experiment be located to most efficiently be maintained over the long term?

Consider the potential complexity of locating experimental plots within a larger area. To exemplify the complexity of plot location, consider the Allwine Prairie long-term research plots at Glacier Creek Preserve. The experimental units were established along a north-facing slope because it was out of sight of a road and because of ease of access from an internal fire road. The lead author has since learned that controlled burning on these slopes is complicated by 2 factors. First, during spring burns, experimental units are on the leeward side of the hill mass resulting in winds that commonly swirl irregularly across the units. These wind conditions vary the rate and, to some extent, the direction of movement of the fire front across units. Secondly, to establish the back-fire needed to control fire spread, fires need to be ignited downwind, which, in the spring, is along the lower-slope portion of units. Under these conditions, care has had to be taken to ensure that wind speed and direction is sufficient to offset the tendency of fire to move rapidly upslope. Locating the experiment at a more level site on the preserve, while less easily accessed, would have avoided this annual fire-control issue. Experimental units at the replicate site at Mead, Nebraska (see below), however, were situated on flat terrain where wind direction and slope effects are not issues.

Consider personnel. Do you have trained personnel who can apply appropriate management, particularly when treatments include the application of fire in small areas such as experimental units? It is not as much about formal fire certification (though this is increasingly a concern as prescribed fire is subjected to greater scrutiny) as it is about having the experience needed to conduct the burn treatments that might be required for a long-term fire study.

Design a sampling protocol with the following considerations:

- Set up a sampling protocol that can be conducted equally and accurately by adequately trained but different individuals over the years. Consider incorporating quality assurance/quality control checks into data collection.
- Ensure that your sampling protocol allows for comparison with other studies. A network of sites collecting data in a way that allows for comparability will greatly add to how well results can be extrapolated across a region. The

absence of a common sampling protocol, however, does not preclude conducting other types of sampling at any site, so long as some data are collected in a way that can be compared with other sites. Ideally, this involves a cooperative decision about what type of data to collect among sites within a network. Such criteria have been coordinated among the global and national LTER research programs discussed above and are a goal of the type of fire network proposed in this paper.

- Consider synchronicity of plot sampling across the region. Will all sites be sampled at the same time or will sampling be based on some phenological state of growth or on some other factor? Consider the implications of asynchrony for analysis and interpretation.
- Avoid altering design. Avoid changing your experimental design once treatments have begun! That said, changes earlier in a study are less likely to be an issue than those made several years into a study. Changes in treatment effectively reset the study back to Year 1, so it is crucial to think carefully through all details of the long-term study before initiating treatments. If you do need to make changes in the experimental design, be sure you understand the logic for doing so and, then document that logic (in writing) for future reference.
- Consider cost. Some cost factors to consider are those associated with initial setup, ongoing management or experimental treatments, and sampling effort. Some means of ensuring that sampling will be conducted over the years as scheduled is a consideration that may involve a budget expense for hiring and retaining an adequate number of trained technicians.

Considerations in Establishing a Long-Term Study

While there are various considerations in establishing and implementing any research project, the following points are those drawn from the lead author's experience in specifically establishing a set of long-term research plots at Glacier Creek Preserve, which is further described in the Case Study section below. The points, some of which were already discussed, are a combination of what was done and possible improvements as determined with the benefit of hindsight.

Research objective.—A written objective will help you decide if you need to conduct a long-term study to obtain the information in which you are interested. Establishing objectives is the first critical step and needs careful thought since the objective determines the details of the project. In addition to other considerations, the researcher should engage land managers when developing a long-term research project to ensure it benefits their decision making needs as well as accomplishing specific research objectives. Experiments require explicit hypotheses and data are used to test models. The concept of "mental models" is one bridge between research and practice—this concept recognizes that practitioners base their management decisions on conceptual models and hypotheses that may or may not be explicitly stated. Some research in sustainable agriculture has found that practitioners' mental models better predicted the outcomes of experimental treatments than researcher's models (Halbrendt et al. 2014). Bridging research and management communities requires significant investments of time by both parties. Frequent discussions between researchers and practitioners are important for building trust and identifying differences in theoretical models and mental models (Lyon et al. 2010).

Study site.—Identify a location where you can conduct the study. Be sure that the proposed study site is in a desired ecological state. Site features to consider include whether the site has adequately established vegetation, uniform soil conditions (or sufficient data on soil variations), and suitable topographic conditions (e.g., aspect and slope). These are important considerations since variability among different experimental units can, for example, affect long-term maintenance of treatment plots (e.g., different fire behaviors) or complicate interpreting results. Part of determining an appropriate study site is to consider whether you will need to obtain permission, permits, or meet any administrative requirements associated with the potential site. In the United States, different states and districts within states have varying requirements and permits needed to conduct prescribed burning (e.g., applying treatments to plots). Be sure to review these requirements carefully and, if possible, discuss your project with individuals at the relevant organizations or agencies, and do so before spending much time setting up the study. A working relationship between the fire researcher and those providing approval will greatly facilitate the conduct of long-term fire studies.

Statistical considerations.—Ideally, the basic concept is to develop a statistical protocol for testing and analysis before collecting field data. Having this protocol will help avoid either collecting insufficient data for statistical testing or spending excessive time collecting more data than are necessary for statistical analysis. In particular, consider factors such as the number of experimental units and sampling intensity needed for suitable statistical testing since this will assist in most efficiently collecting data. Do not unknowingly collect more data than necessary for statistical analysis. For long-term plot data, a repeated measures ANOVA is likely to be an appropriate test but there are other tests that may be more suited to the members of the network, and these need to be agreed upon early in the process of data collection. Where studies are already initiated, a review of their sampling protocol is necessary to assess if previously collected data are appropriate to the protocol developed by the network.

Pretreatment assessment—To best assess fire effects, it is essential to collect pretreatment data in each plot on as many biotic and abiotic variables as possible, doing so over as many years before initial plot treatment as is practical. During the time pretreatment data are being collected, all plots should be identically managed. Among considerations for pretreatment sampling would be determining initial species composition, with the desired result being that initial differences among treatment plots are not significant. Other considerations include quantifying soil characteristics and ecological processes such as soil respiration, nitrogen flux, etc. More is better than less since unneeded pretreatment samples and data can be discarded but there is no going back to collect pretreatment data once treatment application has begun.

Initiate treatment.—Initiate treatment or, for preserve-wide long-term studies, initiate or continue long-term management. Consider recording information on treatment conditions such as the on-site weather conditions at the time of burning, phenology of keystone plant species for management conducted during the growing season, fuel load and moisture (collect samples clipped before each burn), and postfire treatment effects (i.e., remaining fuel). Selecting which, if any, conditions to document should be guided by the study or management objectives. Be sure to organize or record data collected to facilitate relocating data when needed.

Initial posttreatment response.—Initial responses to a treatment may differ from responses to the same treatment when applied in subsequent years. Moreover, these differences may continue between treatment applications until the plant community has reached some level of stability for the environmental conditions resulting from any given treatment. If short-term responses are important to your research question, collect data immediately after the initial treatment (e.g., sample vegetation at the end of the first growing season following treatment), and for as many years thereafter that you think will continue to provide useful information. The National Park Service monitoring protocol, for example, recommends sampling immediately after a fire and then at 1, 2, 5, and 10 y after burning (USDI NPS 2003), although posttreatment sampling frequency elsewhere is largely a function of the study objective. At some point in time, should other priorities not allow time for annual sampling, develop a logical rationale for less-frequent sampling that will withstand scrutiny by those conducting similar research. At Glacier Creek Preserve, given the length of time to sample all research plots, the approach has been to sample one experimental unit of each replicated treatment each year. We conduct a full evaluation of all experimental units the year before quadrennial burn treatments (the longest time for plant recovery in the 4-y burn treatment), and the year after quadrennial burn treatments (the immediate response to a year's treatment). More about the design of this study is given in the Case Study section below.

Do not stop.—It may take a few years to develop the schedule for treating plots into your "management memory" (i.e., remembering to apply treatments appropriately on the schedule designed) but it is important to ensure treatment application over time. Like sampling, application of treatments should have a sufficiently high priority to be accomplished on schedule and with regularity.

CASE STUDY: GLACIER CREEK PRESERVE

The UNO's Glacier Creek Preserve is one example that may serve as a model for long-term ecological fire research.

Case Study: Background

Glacier Creek Preserve is a 172-ha (424-acre) prairie preserve situated in eastern Nebraska. The preserve's development started with the 1959 donation of the 65-ha (160-acre) Glen Haven Farm to the Biology Department at UNO (at the time, Omaha University). In 1970, 57 ha (140 acres) that had been in agriculture for decades was seeded to native grasses, at which time the farm was renamed Allwine Prairie Preserve after Arthur and Antoinette Allwine, who made the land donation. Between 2009 and 2016, 107 ha (264 acres) of surrounding agricultural land were acquired and added to the preserve which, when combined with Allwine Prairie Preserve (now referred to as the Allwine Prairie Tract), constitutes today's Glacier Creek Preserve, a preserve at the rural–urban boundary that incorporates an entire subwatershed. Land acquisition was made possible by significant donations from Barbi Hayes, a private donor who also donated an education and research building at the preserve (The Barn at Glacier Creek), as well as from the Nebraska Environmental Trust, the Papio-Missouri River Natural Resources District, and UNO. UNO provides significant long-term support maintaining 2 staff specialists, one addressing outreach and administrative needs and the other, a resident caretaker, responsible for land management. The preserve has been supported by a succession of university administrators from the chancellor, to the dean of Arts and Sciences, to the department chair. The newly acquired land presently remains in agricultural production but is scheduled for restoration to tallgrass prairie or associated habitats over the next few years, as resources permit.

Case Study: Objective

The overall objective of the preserve is to maintain a large, ecologically functioning tallgrass prairie ecosystem in the region that provides opportunities for research but that is also widely available for use by organizations, classes from all grade levels, as well as by the casual visitor who can walk the preserve and get the feel of our tallgrass prairie heritage.

Figure 2. An aerial view of the 3-ha (7-acre) area at Glacier Creek Preserve in which long-term research plots were established in 1978.

Case Study: Allwine Prairie Preserve and Long-Term Research

The original 65-ha (160-acre) Glen Haven Farm had been in agricultural production for more than 100 y, most recently rotating annually between corn (*Zea mays*) and soybean (*Glycine max*), although a few hectares were in red clover (*Trifolium pratense*) at the time of the donation. In 1970, 57 ha (140 acres) of the farm were seeded to what, at the time, was considered to be the "big 5" grasses, all of which are warm-season (C_4) species: big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), switchgrass (*Panicum virgatum*), Indiangrass (*Sorghastrum nutans*), and sideoats grama (*Bouteloua curtipendula*). This seed mix was uniformly scattered across hills of the upland portions of the preserve. While not by design, the restoration, then called Allwine Prairie Preserve, may have been among the largest tallgrass prairie restorations in region at the time. This restoration set in motion the initiation in 1978 of what we believe to be among the longest-running, continuously maintained, replicated set of fire and mow treatment plots in the region. These plots have been continuously treated, basically as originally planned.

Since 1970, efforts continue to focus on increasing plant diversity of the 57-ha restoration using various approaches, from sod and individual plant transplants, to scattering locally collected seeds, to planting greenhouse-raised seedlings. Managed with a 3-y fire return interval during midspring (i.e., burning a third of the preserve around May each year), today's reconstructed prairie preserve, which includes a creek and some wetland and wooded areas, supports more than 340 species of vascular plants, of which 228 are associated with the prairie. In addition, the preserve supports 129 species of birds, 12 species of amphibians and reptiles, 30 species of mammals, and an undetermined number of invertebrates, including a large population of the regal fritillary butterfly (*Speyeria idalia*), indicative of a viable tallgrass prairie restoration.

Case Study: Results of Long-Term Research

As discussed above, long-term research can occur at 2 basic levels: (1) site-wide and (2) experimental units. At the Allwine Prairie Tract of Glacier Creek Preserve, we have focused on documenting changes on the restoration as a whole (e.g., site-wide assessments measuring the restoration's response to spring burns at 3-y intervals) and changes in treatment within experimental units, which focus on different seasons and frequencies of burning and mowing. Details included in the following discussion are to provide some perspective of the kinds of issues that might warrant consideration by others planning long-term research efforts.

Case Study: Preserve-Wide Long-Term Ecological Research

Since, from the outset, we were interested in long-term plant community dynamics, plant community composition was sampled across the entire 57-ha restoration in 1975, 1993, and 2009. Vegetation was sampled by species and plant groupings (graminoids, forbs, woody, litter) in 25 2-m-diameter circular plots randomly located at each of 17 locations across the preserve. These 17 sample locations were chosen to represent all topographic locations and aspects situated on the preserve. In 2009, the 17 general sample locations were identified using global positioning system (GPS) coordinates, but for the earlier studies, without the benefit of GPS, sketch maps were used to indicate and approximately relocate sample points. Data from these years provided information that would be difficult to assess in any short term. For example, while the restored area was uniformly seeded in 1970, by 2009, data from more xeric south-facing slopes indicated that big bluestem, which is best suited to more mesic conditions, decreased from 39% cover to 24% cover, whereas little bluestem, more suited to xeric conditions, increased from 6% to 21% cover. Among other benefits, this type of long-term study may help direct more efficient distribution of seeds during reconstruction, for example, deciding where to plant specific species, or, over a much longer time period, these data may document plant community responses to environmental changes such as may occur with climate change.

Case Study: Research Using Experimental Units

Setup.—In 1978, 45 experimental units were established within a 3-ha (7-acre) portion of the 1970 restoration with the objective being to assess the long-term effects of the season and frequency of burning and mowing on tallgrass prairie (Figure 2). Experimental units were established on a

Figure 3. A spring burn begins on an experimental unit at Glacier Creek Preserve. Volunteers are key to providing capacity to burn during multiple seasons each year.

slope with aspects varying from east to north and steepness varying from 6% to 16%. Soils of the plots were primarily loess-based, silty clay loams and clay loams of either the Burchard-Contrary-Steinauer complex, or the Contrary-Marshall silty clay loam complex (USDA NRCS 2017). Three replicate plots, of comparable size, were designated for each of 8 fire treatments, 7 mulch–mowing treatments, and 1 untreated "control." Mowing treatments mirrored the season and frequency of fire treatments, with both treatments applied either annually or quadrennially and in the spring (ca. 1 May), summer (ca. 1 July), or fall (after the first hard freeze, usually in November or December) (Figure 3). Plant composition in each experimental unit was assessed in 10 quadrats located along an 11-m-long transect centered in each unit and oriented from upslope to downslope. The transects were marked with metal end-poles.

Because the initial restoration included only warm-season (C_4) grasses in the mix, 3 individual plants of porcupine grass (*Hesperostipa spartea*), a cool-season (C_3) grass, were transplanted to the center of each experimental unit in 1978 (source: a local prairie scheduled for destruction). All 3 porcupine grass plants were clustered at the 5-m mark of the 11-m-long upslope-to-downslope transect used for plant composition sampling (see below for more details). Subsequently, sampling found that sedges (*Carex* spp), another cool-season (C_3) graminoid, were introduced via the porcupine grass transplant to 44 of the 45 experimental units. In addition, to add a forb component to the grass-dominated site, in the fall of 1979, locally collected seed of 8 prairie species was sown at right angles to and approximately 1.5 m on either side of the 11-m transect. Scattering was approximately equally spaced from upslope to the downslope pole. Black-eyed Susan (*Rudbeckia hirta*) was scattered at right angles to the upslope pole, followed in succession by heath aster (*Symphyotrichum ericoides*), tall cinquefoil (*Potentilla arguta*), white wild indigo (*Baptisia alba*), Illinois tickclover (*Desmodium illinoiense*), leadplant (*Amorpha canescens*), downy gentian (*Gentiana puberulenta*), and, at the downslope pole, white prairie clover (*Dalea candida*). In November 2011, seeds of grayhead coneflower (*Ratibida pinnata*), Canada wild rye (*Elymus canadensis*), and western ironweed (*Vernonia baldwinii*) were scattered as in 1979 with grayhead coneflower at the upper pole down to western ironweed at the midpoint of each transect. Other than removing woody plants, which are known to invade tallgrass prairie (e.g., Bragg and Hulbert 1976), no attempt was made to prevent immigration and establishment of any species within or between the experimental units.

Evaluation.—Experimental units were evaluated in 1979 and 1981 to establish a pretreatment baseline for species composition. However, while we collected and analyzed soil conditions (soil pH, excess lime, residual nitrate, phosphorous, potassium, texture, and soil organic matter) at sites across the preserve, we did not do so within each experimental unit, an omission that we recommend not be duplicated in any long-term plot sampling. Pretreatment soil conditions, including processes such as soil respiration, provide useful data when assessing treatment-effect differences in the future. It is important to have documented initial conditions since, without baseline soil samples, it is difficult to separate natural soil variability from the effects of treatment.

Plant composition in each experimental unit was, and continues to be, assessed using ten 30- × 50-cm quadrats systematically located along each of the 11-m long transects centrally located within each experimental unit. Transects were oriented from upslope to downslope and permanently marked with metal end-poles for subsequent relocation. Quadrat size was based on what, at the time, was a standard size used in various grassland studies. This sampling quadrat size (30 × 50 cm) is still used because of the positive relationship between area sampled and plant species diversity—changing the size would complicate comparing diversity among years. The number of subsamples (10 quadrats in each experimental unit) was determined using a preliminary study in which 80% of the species observed within a plot were recorded using this number of quadrats. Within each experimental unit, quadrats were placed systematically rather than randomly. Due to topography, experimental units varied in size from 0.035 to 0.174 ha (0.086–0.430 acres). Sampling consisted of recording the canopy cover and the percentage of total current-year's growth for each species and species group (i.e., graminoids, forbs, and woody plants) (e.g., modified from Daubenmire 1959).

Preburn sampling included clipping all fuel from three 30- × 50-cm plots located in upper, mid, and lower slope locations within each experimental unit before it was burned. Collected material was weighed, oven-dried, and reweighed to quantify fuel load and fuel moisture. Estimates of flame height were also recorded during the burns. In addition, atmospheric conditions (temperature, relative humidity, and wind speed and direction) were recorded at the time of the burn.

Case Study: Long-Term Results

The overall purpose of this paper is not about specific results from Glacier Creek Preserve but rather about the kind of information that long-term studies, particularly a network of long-term research sites, might contribute to knowledge about effects of management. As discussed earlier, the effects of any management regime are likely to vary across an ecoregion, which speaks to the advantage of a network of sites and replication, where possible. Beyond that, though, some results of specific management regimes may only be known through long-term study. For example, significant frequency-by-season interactions on species composition among treatments at Glacier Creek Preserve were not detected until 25 y into the study (Dickson et al., unpublished data). Additionally, it seems likely that many years were required before long-term treatments differentially affected soil processes such as infiltration rates (e.g., Schacht et al. 1996) or populations of microorganisms, such as soil fungal and bacterial communities (e.g., preliminary research in 2015 by UNO's Lifeng Zhu et al., unpublished data). These types of results were neither anticipated nor likely to have been hypothesized in 1978, examples of how long-term data may facilitate new hypotheses and sampling methods.

Case Study: Replication

While not discussed elsewhere, a 4.5-ha (11-acre) replicate study area is located at the University of Nebraska–Lincoln Agricultural Research and Development Center situated south of Mead, Nebraska. This site, located approximately 48 km (30 miles) southwest of Glacier Creek Preserve, was established in 1981 using 39 0.1-ha (0.25-acre) experimental units, with management mirroring the experimental design at Glacier Creek Preserve's Allwine Prairie Tract. Replication is an important statistical and practical consideration, so establishing this site added value to the long-term study at Glacier Creek Preserve. In this instance, differences in initial plant composition—reflected mostly in the abundance of smooth brome (*Bromus inermis*) at the Mead site—is thought to be the main factor driving very different results for similar treatments over the same period (Bragg, personal observation and unpublished data). This preliminary, albeit general, result emphasizes the value of both replication and of a network of long-term studies allowing land managers situated across the same ecoregion to better assess potential effects of particular treatments and initial conditions (e.g., plant species composition) on their specific site.

Case Study: Concluding Comments

Glacier Creek Preserve is one example of a long-term research project. Other locations maintaining comparable projects, however, need to be identified and offered the opportunity to join the conversation. A network of such sites could benefit land management efforts by comparing details of establishment, functioning, and data collection among sites to identify lessons that could learned from each other.

2016 NORTH AMERICAN PRAIRIE CONFERENCE BREAKOUT SESSION

The need for fire-effects information was discussed during a breakout discussion session at the 2016 North American Prairie Conference, where researchers and land managers also shared their opinions on how the potential costs and benefits of developing a research network with experimental treatments could be relevant to management needs. Among highlights of this discussion were the following:

- Representatives from colleges and universities strongly agreed that implementing a set of standard fire management comparison treatments and collecting data with a standardized protocol would add value to their work. One participant, however, noted that involvement would depend on how complicated it would be to implement and sustain the effort.
- Regarding fire timing, some researchers reported that they are collecting data on life-form phenology at the time of burning. Some also collect data on fire effects on plant communities and responses of wildlife.
- Variables that are important when translating information to fire practitioners are fire weather, fuels, and fire behavior. Of these, fire weather is not recorded consistently, and, except as mentioned above for plots at Glacier Creek Preserve, no colleges or universities reported collecting data on fuels or fire behavior.
- An unexpected outcome was that several participants suggested support for stronger partnerships between researchers and practitioners. For example, one specific suggestion was for TPOS to develop a list of land managers who can accommodate research on their sites, since researchers may not be reaching out to the correct individuals when seeking collaborators on applied research.

Next Steps

There are likely to be complications to developing a prairie fire research network, especially one that addresses land management decisions. Consequently, we suggest that, in the short term (2 to 3 y), sustained efforts are needed to create awareness of this concept; to facilitate discussion and debate among researchers, land management decision makers, and funders; and to support pilot collaborations. We also recommend further investigation of the benefits and risks of engaging in and funding of a regional fire research network to promote long-term relevance to managers, scientific rigor, and sustainability. Components of this vision can be supported by the TPOS consortium, though the consortium cannot maintain the activity alone. Some supporting actions could include the following:

- a collaboration (in progress) between TPOS and UW-Platteville to document potential network locations (e.g., field stations) that include tallgrass prairie reconstructions or management in their research and outreach activities. This effort extends across the TPOS region and slightly beyond to include a 97-km (60-mile) buffer in the United States and that portion of the ecoregion in Ontario and Manitoba, Canada;
- a webinar series to share current long-term fire management research and increase awareness of the concept;
- field tours hosted by current research sites investigating fire season and frequency;
- encouraging a current graduate student to write a review of the region's fire season and frequency research for a thesis/dissertation chapter;
- developing white papers to inform potential research funders about the current state of knowledge, information needs, and benefits and risks of funding future network-based fire regime research in the TPOS region; and
- developing a keystone strategy uniting many of the pieces above by collaborating with partners to develop a series of organized sessions at conferences with overlapping organizers and participants.

Regarding the final bullet (above), we hypothesize that a series of organized sessions can influence the following outcomes: (1) we can increase awareness of the concept by bringing the idea to researchers in different parts of the region and diverse disciplines, (2) we can share current knowledge, (3) we can investigate and identify knowledge gaps, and (4) we can increase debate and participation across relevant disciplines, such as the Society for Ecological Restoration Midwest/Great Lakes Chapter, North America Congress for Conservation Biology, and Midwest Fish and Wildlife Conference. Overall, such a keystone activity would support frequent discussion among core participants, enlarge the network of interested researchers, and ensure the concept remains open to further development, critique, and refinement. Due to the open-ended nature of these activities, participants might want to consider some sort of a charter or other agreement to establish various logistical issues, such as how applications for funding opportunities will be jointly proposed and administered.

Several questions at our breakout session indicated that researchers are hesitant to pursue this concept without any up-front funding available. Currently, no startup funding is available through the TPOS consortium, nor, to our knowledge, are other funds available. The value in participating in further unfunded activities, however, is that participation builds relationships needed to take advantage of funding opportunities on relatively short notice. For example, the Joint Fire Science Program's funding opportunity, open from 15 September to 17 November 2016, included research on fire effects on herbaceous and shrub species, and funders were "...interested in proposals that through laboratory and field experiments further our understanding of the direct effects of heat from fire on a variety of herbaceous and shrub species under different environmental conditions and across different geographic areas" (JFSP 2017). Had a nascent network of researchers and managers already existed in the tallgrass prairie region at the time, the group may have been well prepared to pursue this funding opportunity to develop part of a fire research network.

CONCLUSION

Creating a network of long-term research projects focusing on the effects of fire would be valuable for informing local land management decisions. Such research would help clarify interactions between fire regimes (e.g., burn frequency and season) and variations in soils, weather, climate, and biodiversity. Long-term research conducted by UNO at the Glacier Creek Preserve can serve as a successful model for others in the region to follow. Bringing collaborators together and creating standard research methods and protocols are important future steps for creating a network of long-term research projects.

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