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porcelain and wood sculpture

A new decision support tool for collaborative adaptive vegetation management in northern Great Plains national parks

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Abstract

National Park Service (NPS) units in the northern Great Plains (NGP) were established to preserve and interpret the history of America, protect and showcase unusual geology and paleontology, and provide a home for vanishing large wildlife. A unifying feature among these national parks, monuments, and historic sites is mixed-grass prairie, which not only provides background scenery but is the very foundation of many park missions. As recognition of the prairie's importance to park fundamental resources and values has grown, so too has the realization that invasive plants threaten these values by reducing native species diversity, altering food webs, and marring the visitor experience. Parks manage invasive species despite uncertainties in treatment effectiveness because management cannot wait for research to provide definitive answers. Under these circumstances, adaptive management (AM) is an appropriate approach. In the NGP, we formed a collaborative adaptive vegetation management team to apply AM towards reducing invasive species (with a focus on exotic annual grasses) and improving native vegetation conditions. In our AM framework, the team uses a Bayesian model built from NPS Inventory & Monitoring and Fire Effects monitoring data and experimental results to predict the effects of management actions on park management units, according to those units' vegetation condition and management history. These predictions inform management decisions, which are then applied. Vegetation monitoring data are collected and used to update model parameters, and we apply what we learned from our actions to management planning the following year. We explain how this science-based approach to decision making improves vegetation management over current practices and discuss the challenges we face in its implementation and sustainability.

Introduction

Managing for resilient ecosystems and protecting native species populations have become increasingly difficult in the 21st century. In the past few decades, National Park Service (NPS) units (collectively, "national parks") have experienced increasing recreational pressure from growing populations and popularity of outdoor activities; invasive plants, animals, and diseases have continued to spread to wildlands; and extreme weather events are becoming more frequent as the earth continues to warm. Although the traditional NPS approach of trying to maintain ecosystems within their historic range of variability may no longer be relevant, national parks still strive to provide favorable conditions for the native plants and animals they currently harbor or may in the future. Providing these conditions in many cases requires active management, but prescriptive methods for achieving desired results rarely exist.

Management uncertainties and challenges are particularly prevalent in northern Great Plains (NGP) parks. Covering more than 180 million acres in Montana, Wyoming, the Dakotas, Nebraska, and Canada, the historical NGP landscape was dominated by mixed- and shortgrass prairie. By the early 1990s more than 75% of these grasslands had been lost and less than 0.01% were protected (Samson and Knopf 1994). Energy extraction and development and high crop prices have accelerated the rates of loss since then (Wright and Wimberly 2013). At 242,756 acres, Badlands National Park in South Dakota is now one of the largest expanses of protected mixed-grass prairie in the world. Thus, despite the challenges park managers face, maintaining native prairie within park boundaries is important for the continuing existence of this ecosystem.

A triumvirate of drivers—fire, grazing, and climate—shaped the prairies into disturbance-dependent systems (Figure 1). Without fire or grazing, invasive plants—particularly exotic cool-season grasses—encroach and may eventually dominate these grasslands (Porensky et al. 2017). Mimicking these disturbances through management within the confines of a fenced park is challenging. Prescribed fires are restricted to moderate burning conditions in the spring and fall and require substantial skills and resources to execute. Native grazers such as bison may be an effective tool for controlling some invasive species, especially grasses, but parks of less than 3,000 acres are too small to sustain native grazers. Parks large enough to support these wildlife do so, but they struggle to find the right amount of grazing pressure as forage production and water availability vary widely from year to year and as a result large areas of the parks are minimally grazed. Given the critical importance that grazing by large herbivores plays in maintaining native plant community composition in the NGP prairies (Porensky et al. 2017), short-term grazing by domestic livestock may be a viable alternative for park lands that cannot sustain bison. However, using domestic grazers as a tool to reduce the spread of invasive plants is difficult for national parks to implement because it may compromise park cultural and natural landscapes or other sensitive resources. In this context, NGP park managers must take alternative actions to preserve the prairie, including applying herbicides, planting native species, and releasing biological control agents.

In many cases these actions are implemented piecemeal or prioritized based on convenience with a trial-and-error approach, are guided by unstated or vague desired conditions, and/or lack follow-up evaluation of outcomes. Even in the best case, when scientific literature guides management actions with specific objectives and evaluation of outcomes (as with prescribed fires), the means and incentives for incorporating that evaluation into future decision making are limited. Unfortunately, these approaches are not succeeding in preserving native prairie in NGP parks (Ashton et al. 2016). Specifically, monitoring data from parks in the region show that none are dominated by "high-quality" prairie (defined as a diverse mix of native grasses and forbs with low exotic species abundance and low woody density) complemented (in some instances) by areas of high-quality native woodland; instead, their landscapes are often a mixture of "low-quality" prairie or woodland (somewhat-invaded native vegetation lacking high diversity) and areas with high levels of exotic annual or perennial grasses or exotic forbs (Table 1). The poor condition is not because of lack of good intentions or hard work by park managers. Instead, uncertainty about the most effective management strategies in a complex ecosystem, exacerbated by declining funds and personnel in natural resource management programs, combine to challenge preservation and restoration efforts. As the financial costs of treatment and the ecological consequences of doing nothing have increased, a better way of doing business is critically needed.

Collaborative adaptive vegetation management

Two general components are critical to improving vegetation management outcomes in NGP parks: (1) integrating landscape management actions, such as prescribed fire and herbicide applications, and (2) structured learning-by-doing. Integrated pest management (IPM), which has long been stressed as the most effective way to control individual plant species, relies on multiple methods of controlling undesired plant species. For example, effectiveness of some herbicide treatments is improved by reducing plant litter before application; prescribed fire can accomplish this as well as induce mortality of invasive plants directly. However, applying IPM to improve the resilience of whole native ecosystems is rarely undertaken because of its difficulty. Moreover, doing so cannot resolve the uncertainties in management. Adaptive management (AM)—"a formal iterative process of resource management that acknowledges uncertainty and achieves management objectives by increasing system knowledge through a structured feedback process" (Allen et

FIGURE 1. Fire, grazing, and climate have shaped patterns of diversity and production in the mixed-grass prairie. Fire (top) and bison grazing (bottom) drive patterns of vegetation in Wind Cave National Park. Photographs courtesy of the National Park Service.

	Vegetation Condition									
Park	high-quality prairie	low-quality prairie	simplified grassland	exotic annual grassland	exotic perennial grassland	exotic forb land	high-quality woodland	low-quality woodland	exotic annual woodland	exotic perennial woodland
AGFO	0.38	0.50	0.01	0.11	0.00	0.00	0.00	0.00	0.00	0.00
BADL	0.11	0.41	0.01	0.09	0.09	0.28	0.00	0.02	0.00	0.00
DETO	0.02	0.12	0.00	0.00	0.20	0.06	0.02	0.23	0.01	0.36
FOLA	0.01	0.25	0.03	0.39	0.24	0.08	0.00	0.01	0.00	0.00
LIBI	0.00	0.24	0.01	0.12	0.21	0.31	0.00	0.05	0.02	0.04
SCBL	0.12	0.38	0.03	0.31	0.04	0.00	0.01	0.05	0.04	0.01
WICA	0.07	0.21	0.00	0.01	0.15	0.06	0.07	0.25	0.01	0.17

TABLE 1. Probability distributions of overall vegetation condition for northern Great Plains national parks involved in the collaborative adaptive vegetation management program described in this article. Values are derived from 2014–2019 NPS Inventory and Monitoring Program data. The value in a cell represents the probability of the park being in the vegetation condition in the column; values across each row sum to 1.0. The most preferred vegetation condition(s) are high-quality prairie and, where appropriate, woodland (shaded). Vegetation condition categories are specific to the ABAM decision-support tool described below. Park unit codes are as follows: AGFO, Agate Fossil Beds National Monument (Nebraska); BADL, Badlands National Park (South Dakota); DETO, Devils Tower National Monument (Wyoming); FOLA, Fort Laramie National Historic Site (Wyoming); LIBI, Little Bighorn Battlefield National Monument (Montana); SCBL, Scotts Bluff National Monument (Nebraska); WICA, Wind Cave National Park (South Dakota).

al. 2011)—has been encouraged or even mandated in NPS (see *NPS Management Policies 2006*, Sections 2.3.4 and 8.6.8.2) and across the whole Department of the Interior (see *DOI Departmental Manual 522*, 1 February 2008). However, few examples of successful structured AM programs exist because of the many obstacles that even well-intentioned efforts must overcome (Allen and Gunderson 2011).

Despite these impediments, and encouraged by the emerging success of AM in controlling invasive perennial grasses in mixed- and tallgrass prairie in national wildlife refuges (Kobiela et al. 2017), we established a program called NGP CALM (Collaborative Adaptive Landscape Management). This new approach to vegetation management in NGP parks involves superintendents and natural resource managers from seven parks in which invasive annual grasses are currently problematic and NPS has management control (Figure 2),[1] scientists and data managers from the NPS NGP and Rocky Mountain Inventory and Monitoring (I&M) networks (denoted NGPN and ROMN, respectively), management experts from the NGP and regional Fire Management offices, coordinators of the NGP and Northern Rockies Invasive Plant Management Teams (IPMTs), and scientists from the US Geological Survey (USGS). We were inspired to create NGP CALM based on a need for improved communications, collaboration, and coordinated response to the challenges of managing invasive annual grasses. The purpose of NGP CALM is to work across disciplines, parks, and programs to effectively manage the vegetation in the cultural and natural landscapes of the seven parks.

The exotic annual grasses that spurred the development of NGP CALM are cheatgrass (*Bromus tectorum*) and Japanese brome (*B. japonicus*). These Eurasian annual bromes can transform NGP prairies from a seasonally changing, diverse mix of grasses and wildflowers into a uniform carpet that is brown most of the year. They also reduce forage quality and availability for wildlife when they replace more nutritious and longer-lived native grasses. Monitoring data from NGP parks show that, as relative cover of annual bromes increases from 0% to 75%, the number of native plant species drops by at least 50%. Furthermore, in the absence of active management, annual bromes are becoming more abundant in many NGP parks (Ashton et al. 2016). Two other exotic annual grasses, medusahead (*Taeniatherum caput-medusae*) and African wiregrass (*Ventenata dubia*), have recently spread to the NGP and have the potential to cause even more damage than annual bromes. Extensive research on annual bromes has been conducted in drier regions west of the NGP, where these grasses increase fuel continuity, and therefore flammability, of ecosystems adapted to relatively infrequent fires (Brooks et al. 2016). However, our monitoring data supports the less extensive research in the NGP (e.g., Whisenant and Uresk 1990) showing that fire promises to be an effective management tool in the prairies of the NGP, where more productive grasslands evolved with and promoted frequent (every 5–15 years) fire. Many questions about the management use of fire remain, and even more about that of an herbicide (indaziflam) that shows some promise but lacks extensive testing in the NGP. Questions include: How does the timing of treatments influence annual brome

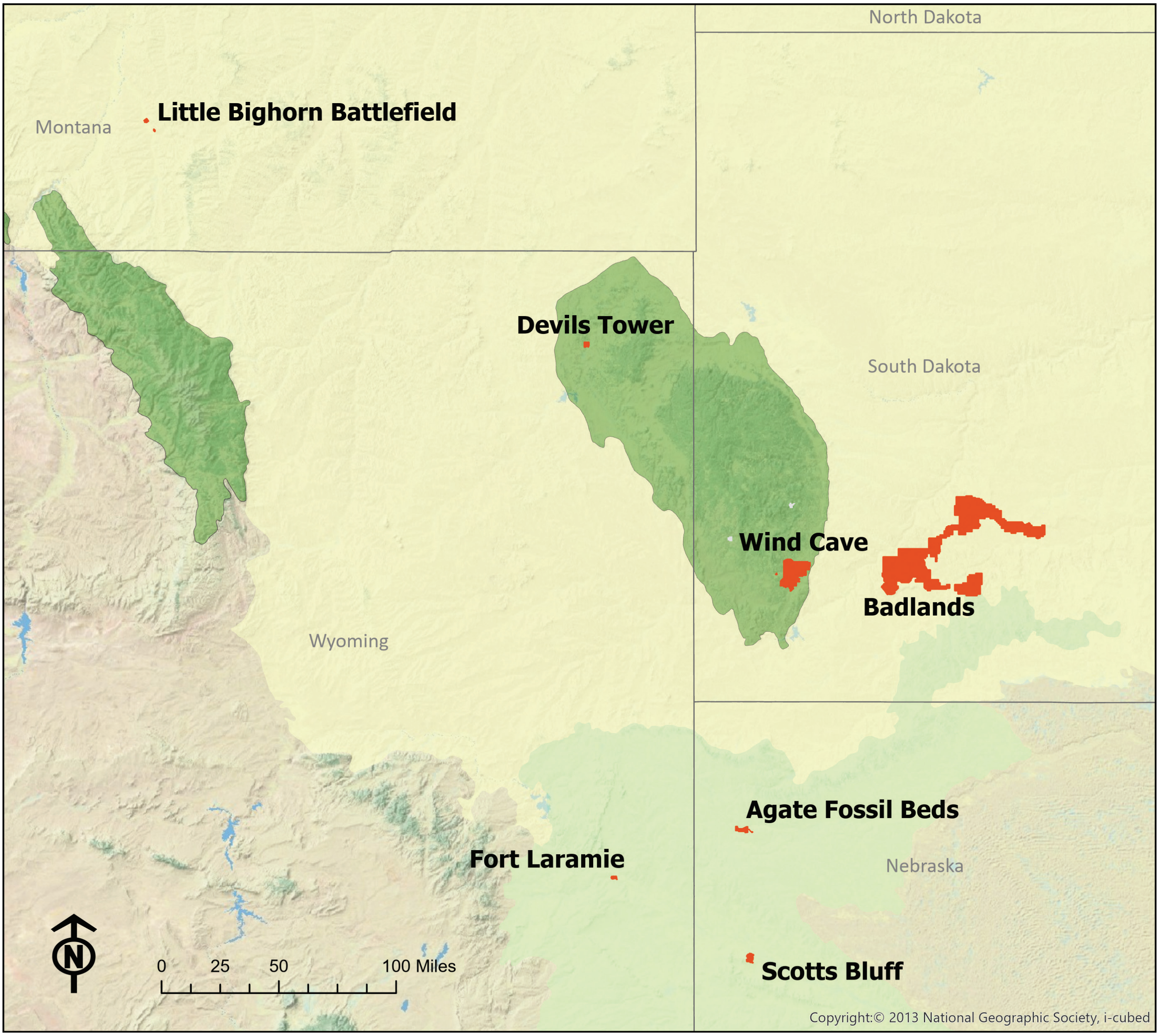

FIGURE 2. Locations of the seven parks collaborating in the NGP CALM.

responses? Is a combination of fire and herbicide treatments necessary, or does either alone suffice? How do management effects vary among different weather and vegetation conditions? How long do treatment effects last? How do you control annual bromes while not exacerbating other invasive plant problems?

Decision framework

To address these and related questions while moving forward with vegetation management, and to learn from our actions, we developed an AM approach that can be viewed as an extension of Structured Decision Making (SDM; Runge 2011). This collaborative approach requires developing a set of quantifiable objectives, a list of feasible management options, and a structure for expressing and learning about uncertainties. The primary goal of this decision framework is to improve the condition of native prairie in NGP national parks. The most feasible management options are herbicide application, prescribed fire, or a combination of the two. To guide management decisions and learn from our management actions, we built the ABAM (annual brome adaptive management) decision-support tool, which is a Bayesian network in the form of a state-and-transition model (Rumpff et al. 2011; Figure 3).

In classical statistics, relationships among various components of an ecosystem would be represented by single models for each component of the system. The results and analyses would be focused on point

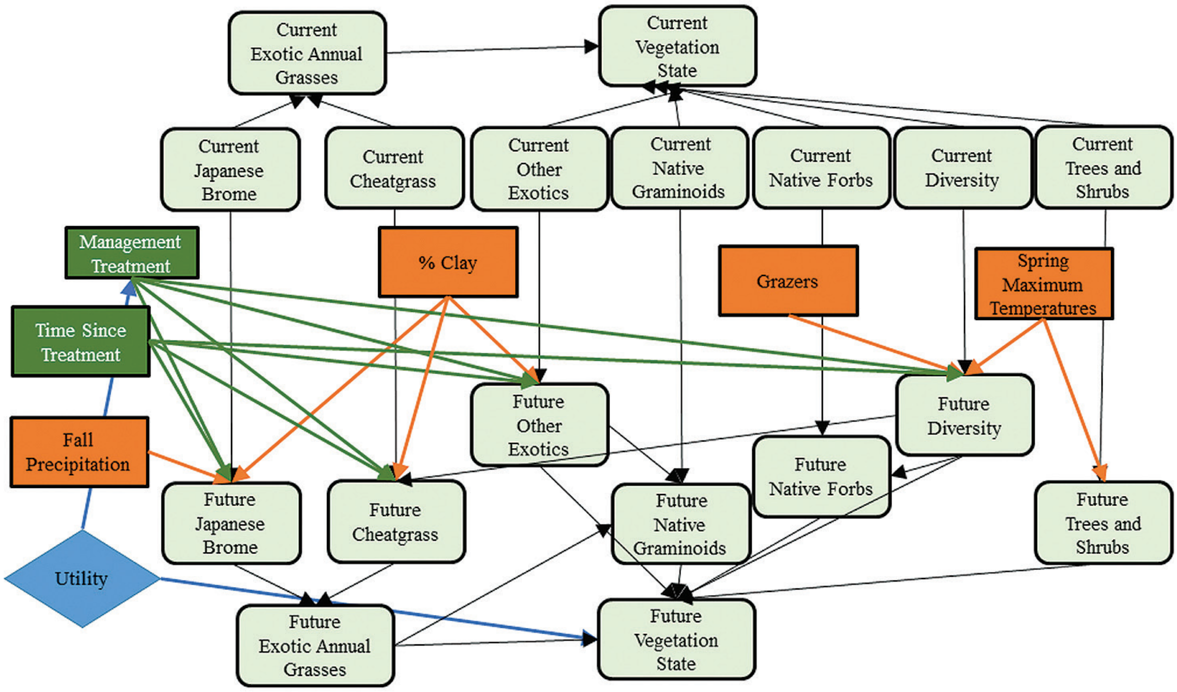

FIGURE 3. Schematic of the ABAM decision-support tool. Pale green boxes (nodes) are vegetation metrics or states, orange nodes are environmental variables with significant effects on vegetation nodes, dark green nodes indicate management actions and time since those actions, and the blue "utility" node contains park-specific preferences for specific vegetation states and weighting of vegetation outcome versus cost of action. Arrows indicate how each node influences other nodes.

estimates, such as means. Bayesian network models, on the other hand, express ecosystem relationships as graphs where multiple components can be represented simultaneously. In addition, these models express those relationships as probability distributions that capture some understanding about system processes as well as the uncertainty in those processes. Because the relationships are expressed as probability distributions, those relationships can be modified using Bayes' theorem, which provides a mechanism for learning. This learning is accomplished by treating the current distributions in the model as "prior information." Monitoring in following years generates new data, which can be combined with prior information, using Bayes' theorem, to produce new, "posterior" distributions (McCarthy and Masters 2005). This updating process can be thought of as the way we reduce the uncertainties associated with future decisions as more information becomes available. As the rate of learning asymptotes (i.e., the probabilities do not change as new data are collected), the model becomes less a learning tool and more a decision-support tool. Bayesian networks are well suited to adaptive management for numerous reasons. They translate well from conceptual diagrams depicting system function, and they can be built from datasets as well as expert knowledge (Nyberg et al. 2006). Bayesian networks are also easily grasped by collaborators and managers.

The ABAM tool considers vegetation metrics in a given park management unit. A "management unit" is a portion of a park that receives the same management action at the same time. The vegetation metrics—native species richness, tree density, and relative cover of annual bromes, other exotic species, native graminoids, native forbs, and shrubs (Figure 3)—are calculated directly from monitoring data collected by NGPN, ROMN and NGP Fire Effects programs. The ABAM tool translates those values from monitoring plots within a defined management unit into a probability distribution to describe the unit's current condition. (Table 1 presents such distributions for each park as a whole.) Considering a unit's current condition, the ABAM tool then produces a prediction of how that condition will change when one of 14 different management actions (combinations of fire and herbicide application at different times in a season) are applied. The uncertainty in the changes in condition is represented as a probability distribution of different possible vegetation states. These changes are influenced by environmental variables such as weather and grazing. The ABAM tool predicts vegetation changes one, three, and five years into the future.

At the outset of the development of this collaborative, the managers expressed their primary objectives as increasing the vegetation quality in their respective parks and reducing management costs. The sentiment behind these objectives was that managers would like to find actions that are cost efficient. The ABAM tool is customized to individual park preferences and calculates the total utility of each management action as a weighted sum of these two objectives. The management action with the highest utility is designated "optimal." For example, the most preferred vegetation state in all parks is "high-quality prairie" (or "high-quality woodland" in those portions of parks where trees are a natural part of the landscape), and the most preferred management cost is $0, which is associated with taking no action. Since the tool most often suggests that achieving or maintaining high-quality prairie requires action, there is a trade-off between achieving desired vegetation conditions and lowering management costs. At this time, when the vegetation condition in these parks is mostly far from the desired state (Table 1) and there is much to learn about the effects of different management actions, we are focusing on assessing which management actions will lead to better vegetation quality and treating cost simply as a constraint (budgets limit which actions can be considered). In short, we currently are not including the cost objective in the calculation of utility. We envision that the cost trade-off will become more important in supporting decisions after more learning has taken place and management shifts toward maintaining, rather than achieving, improved vegetation conditions.

Decision-support tool

The ABAM tool is somewhat unusual in the AM arena in that its initial structure was derived from location-specific data, as opposed to relying on expert opinion and hypotheses. Specifically, we used over 20 years of monitoring data collected by NGPN, ROMN, and NGP Fire Effects and a plethora of potential environmental predictors to determine the model's structure. This included using the bnlearn package in R (Scutari 2017) to explore multiple model structures and using averaging to find a model that captured patterns in the monitoring data. This process identified four environmental drivers—spring maximum temperature, fall precipitation, grazing, and soil texture (designated "% clay" in Figure 3)—that most strongly influence vegetation dynamics. To parameterize the model's predictions of management action effects, we supplemented the monitoring data with data from relevant experiments recently conducted in some NGP parks (hard evidence), as well as simulated data (soft evidence). The simulated data were generated using estimates from published experiments relevant to management actions for which no NGP data exist and that lack information for many of the model's variables (e.g., Sebastian and Nissen 2016). This structure and parameterization are simply the starting point, however, and it reflects the uncertainty about management effects that prompted us to form NGP CALM in the first place.

We are using the ABAM tool in an annual AM cycle of recommendation, management application, post-application monitoring, and updating decision tool parameters from the new monitoring data. We started the process in early 2019. Each winter, we present information about the current condition of management units and their associated recommendations from the ABAM tool to park managers in a vegetation management planning meeting. At this meeting, which includes representatives from the IPMT, I&M network, and Fire Effects program that serve the park, participants use ABAM output to decide which management units to treat and with which management action. This decision will require balancing the benefits of applying optimal management actions to achieve the highest utility against applying an action that provides the most learning (i.e., deciding to use management actions that have not yet been applied). Over time, as the ABAM tool incorporates information from more and different management actions across a range of vegetation conditions, this trade-off should decrease, the utility of different management actions in different vegetation conditions should become more distinct, and vegetation conditions in the parks should improve. When no actions are taken, monitoring data will still be collected and the model will continue to learn and improve, albeit more slowly and confined to components of the model not associated with management actions. By spreading our efforts across seven national parks, we have maximized the chance that at least some management actions will occur each year and the uncertainty associated with model output and subsequent management actions will decrease.

Moving forward

To our knowledge, application of this type of decision tool to guide vegetation management is unique within NPS, and the close collaboration among different NPS programs (fire, I&M, IPMT), USGS, and individual parks is relatively rare. Why is this unusual within NPS? The collaborative effort was certainly bolstered by a large overlap among the different programs' geographic boundaries, an early collaboration between I&M and fire programs that integrated their vegetation monitoring, the close proximity (even shared office space) of the people involved, and, ultimately, by a shared threat to park resources. Even with these advantages, NGP CALM is still challenged, as all managers and scientists involved pass through significant learning curves about data, methods, operations, and business models. The AM approach, particularly with a quantitative decision support tool, requires an investment of funds and personnel from across disparate programs and agencies. It also entails significant communication to ensure all involved understand the tool's capabilities and limitations. Finally, sustaining the approach over the long term requires a willingness from all involved to adopt a new way of decision making and planning, and to accept that learning will take time. For NPS, it is a new management approach in which we recognize uncertainty and measure success as an increase in satisfaction with the overall vegetation condition of the parks rather than acres of individual species treated. These expectations are ideally balanced by the fact that a delayed learning process based on a documented, science-driven process is better than no learning, and that collaboration ultimately improves efficiency and outcomes.

Recognizing the logistical, financial, and administrative barriers to implementing NGP CALM with the ABAM tool, we recently completed a structured decision-making process to determine a path for maximizing the likelihood of its continuation. The process highlighted the benefits of pursuing some easily completed actions (e.g., developing standardized compliance checklists to ensure timely completion of management actions, including NGP CALM collaboration in employee performance appraisal plans), as well as higher aspirations, such as securing permanent funding for full-time AM-support personnel within NPS and USGS. Sustaining the collaboration across parks and programs is difficult with staff turnover and even position losses, but we have found that increased communication and support from supervisors can help maintain recognition and enthusiasm, and the collaboration itself provides an element of job satisfaction.

While the ABAM tool and NGP CALM are relatively young, we have already seen great benefits of the collaboration and increased understanding of the effectiveness of different management actions. For instance, when parks and programs have had staff vacancies, NGP CALM has been able to reallocate workloads and support management actions despite reductions in staff. We have also been more successful in leveraging funds by demonstrating that projects in one park can facilitate learning in many others. Perhaps most importantly, we have completed large-scale vegetation treatments and have an established method for learning from these actions and determining whether they have improved vegetation condition. We encourage greater use of a structured AM approach across NPS to tackle the numerous challenges land managers face. NPS is uniquely poised to more widely adapt AM because it has an established monitoring program, management directives, and a large staff of scientists and managers. The structured AM approach facilitates transparent, defensible decisions driven by the best-available science.

Disclaimer and acknowledgments

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the US Government. This work was supported by the National Park Service and the US Geological Survey.

Endnote

1. The other national park units in the NGP region are not part of CALM either because they do not currently have a persistent problem with exotic annual grasses (Fort Union Trading Post National Historic Site, Knife River Indian Villages National Historic Site, and Theodore Roosevelt National Park, all in North Dakota; and Mount Rushmore National Memorial and Jewel Cave National Monument, both in South Dakota), or because NPS does not control the land within their boundaries (Missouri National Recreational River, Nebraska and South Dakota, and Niobrara National Scenic River, Nebraska).

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