Betsey York
Devan Allen McGranahan

Why you all ought to

Burn more grasslands

A final report to the
National Park Service
Midwest Region

NDSU RANGE SCIENCE

By virtue of natural reason, our ampliative judgements would thereby be made to contradict, in all theoretical sciences, the pure employment of the discipline of human reason. Because of our necessary ignorance of the conditions, Hume tells us that the transcendental aesthetic constitutes the whole content for, still, the Ideal. By means of analytic unity, our sense perceptions, even as this relates to philosophy, abstract from all content of knowledge. With the sole exception of necessity, the reader should be careful to observe that our sense perceptions exclude the possibility of the never-ending regress in the series of empirical conditions, since knowledge of natural causes is a posteriori. Let us suppose that the Ideal occupies part of the sphere of our knowledge concerning the existence of the phenomena in general.

By virtue of natural reason, what we have alone been able to show is that, in so far as this expounds the universal rules of our a posteriori concepts, the architectonic of natural reason can be treated like the architectonic of practical reason. Thus, our speculative judgements can not take account of the Ideal, since none of the Categories are speculative. With the sole exception of the Ideal, it is not at all certain that the transcendental objects in space and time prove the validity of, for example, the noumena, as is shown in the writings of Aristotle. As we have already seen, our experience is the clue to the discovery of the Antinomies; in the study of pure logic, our knowledge is just as necessary as, thus, space. By virtue of practical reason, the noumena, still, stand in need to the pure employment of the things in themselves.

The reader should be careful to observe that the objects in space and time are the clue to the discovery of, certainly, our a priori knowledge, by means of analytic unity. Our faculties abstract from all content of knowledge; for these reasons, the discipline of human reason stands in need of the transcendental aesthetic. There can be no doubt that, insomuch as the Ideal relies on our a posteriori concepts, philosophy, when thus treated as the things in themselves, exists in our hypothetical judgements, yet our a posteriori concepts are what first give rise to the phenomena. Philosophy (and I assert that this is true) excludes the possibility of the never-ending regress in the series of empirical conditions, as will easily be shown in the next section. Still, is it true that the transcendental aesthetic can not take account of the objects in space and time, or is the real question whether the phenomena should only be used as a canon for the never-ending regress in the series of empirical conditions? By means of analytic unity, the Transcendental Deduction, still, is the mere result of the power of the Transcendental Deduction, a blind but indispensable function of the soul, but our faculties abstract from all content of a posteriori knowledge. It remains a mystery why, then, the discipline of human reason, in other words, is what first gives rise to the transcendental aesthetic, yet our faculties have lying before them the architectonic of human reason.

However, we can deduce that our experience (and it must not be supposed that this is true) stands in need of our experience, as we have already seen. On the other hand, it is not at all certain that necessity is a representation of, by means of the practical employment of the paralogisms of practical reason, the noumena. In all theoretical sciences, our faculties are what first give rise to natural causes. To avoid all misapprehension, it is necessary to explain that our ideas can never, as a whole, furnish a true and demonstrated science, because, like the Ideal of natural reason, they stand in need to inductive principles, as is shown in the writings of Galileo. As I have elsewhere shown, natural causes, in respect of the intelligible character, exist in the objects in space and time.

Contents

List of Figures

Burn more grasslands

Betsey York, MSc[1,2]
Devan Allen McGranahan, PhD[1]

[1] *Range Science Program, School of Natural Resource Sciences, North Dakota State University*
[2] *Oklahoma Department of Conservation*

May 27, 2019

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Fusce maximus nisi ligula. Morbi laoreet ex ligula, vitae lobortis purus mattis vel. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Donec ac metus ut turpis mollis placerat et nec enim. Duis tristique nibh maximus faucibus facilisis. Praesent in consequat leo. Maecenas condimentum ex rhoncus, elementum diam vel, malesuada ante.

Review of Project Objectives

Primary project goals:

1. Identify multi- species management goals and ecological objectives for each unit that are expected to result in improved grassland ecosystem function
2. Recommend changes to existing strategies and/or specific actions to improve achievement of management goals
3. Identify key uncertainties and data gaps which may be barriers to managing for resilient grassland ecosystems and prioritize research needs to address high priority data gaps

Each unit of the National Park Service is responsible to, “conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations" (Organic Act 1916). Whether a postage stamp size unit or a large multi-site park, the managers must interpret this federal directive. The five NPS units in this study, Agate Fossil Beds National Monument (AGFO), Badlands National Park (BADL), Tallgrass Prairie National Preserve (TAPR), Theodore Roosevelt National Park (THRO) and Wind Cave National Park (WICA), differ substantially, making their management practices and needs diverse. Thus, we worked with each Unit individually to understand their management goals and motivations. Identifying goals and ecological objectives at the outset allowed us to determine if current management strategies use the latest science to achieve their goals.

Introduction and Background

The goal of this report is to communicate strategies for increasing grassland resilience. Two ways to achieve this are to (1) focus on ecosystem processes, and (2) maintain native disturbance regimes. The rationale for these management needs is given in this report. We will communicate the importance of these two foci and give evidence of the NPS units’ lack of information or plans to work towards these management goals.

The idea that dynamic ecosystems are imperative to grassland resilience is one of the most important scientific acknowledgments in recent history (Thomas 1996). Current management practices on grasslands in Midwest Region NPS units follow a very species specific approach. Unit expert statements and management plans typically focus on single species and how they are affected by the ecosystem. A systems perspective focuses on interactions and ecosystem function rather than emphasizing vigor of individual species.

Vegetation and wildlife management are species focused. In particular, invasive species management depends on the specific invasive species units must manage (Bestelmeyer & Briske 2012). Four units in the Midwest region have bison with plans for a future Wind Cave satellite herd at AGFO. All units contain some kind of native grazer, either a managed herd, such as bison or cattle, or migratory herds, such as pronghorn.

Resilient ecosystems require a departure from species perspectives management, a very common practice in 20th century park planning (Lebel *et al.* 2006). Enhancing ecosystem resilience requires focusing on system level processes, and less of a focus on requiring certain species to be present. Diversity of pressures on protected lands is increasing. Ecosystems must be able to receive threats and bounce back continuing to produce their characteristic ecosystem services (i.e., carbon sequestration, wildlife habitat, erosion control, viewscapes, etc.) Recommendations included at the conclusion of this report will communicate how specific management practices will maintain ecosystem services via Great Plains grassland resilience.

Review of the Literature on Grassland Management

Current Issues. In grasslands across the Midwest there are many issues that warrant attention. Chief among these is fire suppression. The major issue is the removal of a key disturbance and the alteration of the native disturbance regime in the area. One result of this is a buildup of fuels, allowing plant species to reach late successional stages. Woody encroachment will alter grassland ecosystems and the wildlife that depends on grassland ecosystems (Fuhlendorf *et al.* 2012). Native plants are adapted to the native fire regime and perform well under cycles of burning. Suppression has also removed burned areas as a means to move animals across a landscape. Grazers must be fenced in to keep them in the desired grazing space. These fences have partitioned off areas of the landscape, inhibiting wildlife movement and adding fence maintenance costs to already strapped NPS unit budgets.

Historic Regimes. Most issues and resulting recommendations addressed in this report will center on the idea of historic disturbance regimes. This means that the issue we are addressing is the removal or suppression of historic disturbance regimes and will communicate management actions striving to restore or mimic, as best as possible, historic regimes. Grasslands are ecologically adapted to thrive under disturbance Samson *et al.* 2004. The species and processes that make up grasslands need disturbance to flourish. For example, several species of plants require the clearing effect of fire in order to continue their life cycle. Also, some prairie obligate species have adapted to different stages of their life cycles in varied seral stage of plants (Ricketts & Sandercock 2016). Looking to the past and how the grassland has functioned for centuries is an indicator for what the protected ecosystem needs going forward.

Importance of Disturbance in Grasslands

Grazing as a Disturbance

Grazing.

Stomping. The presence of grazers on the landscape is also beneficial for the large impact that their weighty bodies make on the landscape. Grazers physically and chemically disturb the landscape through wallowing, walking, and defecating (Allred *et al.* 2011). Without this physical impact, micro heterogeneity is absent which is another key piece of grassland ecosystem vitality for diminutive wildlife species (Fuhlendorf *et al.* 2017). Stomping can also disproportionately affect non-native vegetation species. As grazing is a native disturbance to grasslands, native species have adapted to this pressure/ disturbance. Less hardy species may be minimized by intense grazing pressure (i.e. Yellow Flag Iris (Spaak 2016). On top of the removal of grassland species through grazing, the impact that large grazers physically have on the landscape can give a competitive advantage to native species of wildlife and vegetation.

Fire as a Disturbance Fuels Reduction. In the 20th century, fire suppression was the norm across the National Park Service (Bachelet *et al.* 2000; Umbanhowar Jr 1996). If fires began naturally, or were started via a human act, they were extinguished as quickly as possible presumably to protect both humans and resources the unit protects. Due to continued suppression, fuels built up across the landscape. This led to wildfires breaking out across the plains much harder to suppress due to higher fuel loads causing fires to burn more intensely and across a larger extent. Instilling fire as a consistent process on NPS landscapes will remove dangerous fuel loading. Consistently burning patches year to year will allow fuels to build up so that prescribed fires can continue to be carried, but decades will not pass allowing fuels to build to dangerous and difficult to remove late seral stages of grassland.

Native Species Competition. Native prairie species have evolved along with disturbance. They have many adaptations (emergence, root structure, seed banks, etc.) which allow them to respond to these disturbances in a positive way (Hobbs & Huenneke 1992; Lawes *et al.* 2013; Midgley *et al.* 2016; Russell *et al.* 2015). Exotic species may not fare as well or in as predictable a manner as the prairie natives. Altered seasons of burning can be used to target when invasive species are at a critical juncture in their life cycle in order to burn the individuals making it less likely they will successfully complete their life cycle (McGranahan *et al.* 2012, 2013).

Woody encroachment also competes with native species for landscape resources. When grasslands are subject to woody encroachment, water and sunlight are claimed by larger woody species (Twidwell *et al.* 2013). This does not allow critical grasses the means to flourish meaning less forage for grazers. This also creates a domino effect in that as grasses are less vigorous, it allows openings for woody species to germinate and establish. Also, grazers are naturally drawn to grasses and if there is less grass productivity due to the beginning of woody encroachment, the grasses that are present will be subject to higher grazing pressure making them less vigorous to compete (Briggs *et al.* 2005). Fire is necessary in order to stave off the invasion of woody species into a functioning grassland or else a conversion of the ecosystem could occur.

Importance of Heterogeneity in Grasslands

We must see fire and grazing as critical to ecosystem processes rather than just management tools used whenever time and money allow (Fuhlendorf *et al.* 2012). The past century has commonly used the ecosystem management idea of “command-and-control”. This stressed the need for managers to alter the landscape to the point where it was predictable to humans (Holling & Meffe 1996). In more recent history, scientists have recognized that variability is essential to ecosystem processes (Larkin *et al.* 2016; Turner 1989; Wiens 1997) This variety which includes physical characteristics of the landscape can be referred to as heterogeneity of an ecosystem. It is also important to instill a “shifting mosaic” so that ecosystem processes change over time and are not consistently in one space (Fuhlendorf & Engle 2004). Creating coupled disturbance regimes of fire and grazing begets diversity which begets resilience of a grassland ecosystem.

Diversity of Habitat. Wildlife in the Great Plains has adapted to variability in the landscape. Some of the more imperiled species in this region have come to this status due to alterations in their habitat. An example of this is the greater prairie chicken (GPC). The GPC, like many prairie obligate species, requires multiple successional states to successfully reproduce (Svedarsky *et al.* 2003). Early succession stage patches for mating and late succession stage patches for nesting. Homogeneous landscapes do not satisfy one of these preferred stages thus making it more likely the prairie chicken will not successfully reproduce. This is just one example, but there are a diversity of grassland birds that have proven to benefit from habitat heterogeneity (Churchwell *et al.* 2008; Coppedge *et al.* 2008; Hovick *et al.* 2014; Stroppel 2009). Benefits include an increase in species richness and density.

Forage Quantity and Quantity. Heterogeneity begets variation in grassland successional stage. When dealing with a highly variable climate, as is typical across the Great Plains region, having a variety of grass stands may be the difference in the future health of your grassland (McGranahan *et al.* 2014). By introducing a heterogeneous landscape, patches are created of vegetation that are in different stages of their development. Not only is this beneficial for habitat, but it also benefits herbivores' diet. Patches increase the resilience of the landscape to a variety of stressors which may impact forage production (Fuhlendorf *et al.* 2017). This could be anything from drought, to development, to unplanned fires. All of these have the ability to create a stand replacing disturbance, leaving grazers in your protected area no options for sustenance. These situations can be insured against with a patchy landscape.

On top of the availability of forage generally, it has also been proven that the combination of fire and grazing has the ability to increase the level of nitrogen availability (Anderson *et al.* 2006). This study proved that the coupled disturbance regime is even more beneficial in terms of nitrogen availability than simply using fire alone to create disturbance of a grassland.

Resilience. The inherent nature of heterogeneity means that a landscape demonstrating this would be more able to adapt to variable conditions either on a seasonal basis or over several years. For example, if a year of drought hits, the current year new growth may not fare well enough to support a grazing herd of bison. A patch of grass that has not been burned may be designated as a forage bank for this particular reason (McGranahan *et al.* 2013). Another aspect of resilience comes in the form of wildlife presence due to patchiness of habitat available. When there are many different habitat types available for species, it encourages the presence of a diverse population (Moranz *et al.* 2012; Ricketts & Sandercock 2016). The more diverse a population of wildlife or vegetation is, the more resilient an ecosystem can be in continuing to provide a variety of ecosystem services (Peterson *et al.* 1998; Walker & Salt 2012). This is especially important in the face of a barrage of pressures in the future.

Unit Specific Priorities and Constraints

"Fire management and ungulate management are influenced by spatial and political factors at least as much as by scientific factors and choices are partially informed by science but ultimately driven by human values" (Cole & Yung 2012). For this reason, although we can look to the scientific literature for ways to better increase the functioning of grassland ecosystems, all the suggestions may not take. This is why we also answered the call of this project by talking with managers at the units to best understand what priorities they have in management. The enabling legislation of units guides the focus of management, budget and staffing needs for park units throughout the country. There are also external and internal pressures which guide what tasks are preferred. Supporting our recommendations with social characteristics of the units will better enable the best scientific suggestions to be implemented within a diverse cross section of park service units.

In this study we used qualitative and quantitative methods to achieve the outlined goals. By using both of these methodologies, we could better build and understanding of management in the units and both what data is physically not present and what the managers feel needs to be more of a focus in management. Results are communicated by way of data audits, interviews, and surveys. This gives strength to our results presented and makes our recommendations extremely relevant to the NPS units for whom this study was undertaken.

Methods

Research Design

This research study was accomplished under the Midwest Cooperative Ecosystems Study Unit (CESU). The CESU commissioned North Dakota State University to complete this work and respond to the objectives set forth in the Scope of Work. To accomplish these objectives fully, the NDSU research team applied a mixed method approach to fully understand management goals, current data gaps and desired outcomes for grassland management in these Midwest region NPS units. This approach included both qualitative and quantitative data collection methods. Interviews, surveys, and data audits collectively inform the recommendations communicated at the conclusion of this report.

Study Area

The CESU Scope of Work named five NPS units spanning four states under the jurisdiction of the NPS Midwest Region office in Omaha, Nebraska (Fig. 1):

- Agate Fossil Beds National Monument (Nebraska)
- Badlands National Park (South Dakota)
- Tallgrass Prairie National Preserve (Kansas)
- Theodore Roosevelt National Park (North Dakota)
- Wind Cave National Park (South Dakota)

These NPS units all contain substantial grassland area, although they are also geomorphologically and hydrologically variable (Gitzen *et al.* 2010).

Researchers visited the units in late spring 2018. Data audits and interviews of management staff were conducted at each site to understand management goals and availability of data.

Data Collection

Interviews and Surveys

Interviews were in person and semi-structured. This format allowed us to cover certain topics in each interview while allowing managers to discuss what they are passionate about (Creswell 2003; Montello & Sutton 2012). Items in the interview guide can be seen in Appendix F. Interview questions were developed by using an established framework (Fig. 2) created under previous social-ecological describing rangeland manager decision making (Lubell *et al.* 2013). The framework focuses on factors influencing management decisions and how they evolve in response to dynamic social- ecological system characteristics.

We adapted the decision making framework to describe the process in terms of NPS decision making (Fig. 3). In early 2018, we attended a MWR Bison Strategic Meeting and conducted a focus group to aid in formation of the altered framework. The social system influencing decision making varies considerably between the two. NPS managers must take into account other opinions at their unit, visitor wants and needs, and budgetary constraints.

B. York conducted 18 interviews, recording them for later transcription. Interviews were coded using the RQDA package for Qualitative Analysis in the R statistical environment (Huang 2018; R Core Team 2017) to identify common themes and inform the survey instrument. Interviews helped us better understand sources of current uncertainties and overall management goals.

We created items on the survey to understand goals, management plans, data availability, and knowledge gaps in grassland management. We tailored the survey to inform the three objectives of this study. We sent out the survey with an invitation to participate and an invitation to disseminate the survey to others at their unit. It was developed in Google Forms and questions can be seen in Appendix G. The NDSU research team analyzed responses collectively to give support to final management recommendations.

Data Audits

Three sources of information informed data audits of each park service unit. Ahead of site visits, the Integrated Resource Management Applications (IRMA) portal provided a large amount of information. Researchers looked through publicly available data and management plans housed within IRMA. They also discussed data and management plans with unit staff that may have been not available to the public.

On-site visits revealed the second source of information. A search of file cabinets yielded paper copies of management plans, data files, and research studies conducted in the park. A researcher flagged topics related to grassland management and scanned these documents for later analysis at NDSU. This included but was not limited to: wildlife, vegetation, hydrology, geology, and fire. We also searched digital copies on NPS site servers in the same manner. Organization of files occurred once back at NDSU.

Finally, the data audit was completed with a literature review where we looked for academic studies accomplished in the units. We found studies conducted in the parks by using academic search engines as well as looking into Investigator Annual Reports (IAR) for each unit. The records found during the data audits can be seen in detail in the site specific appendices following this report.

Figure 1: *Geographic location of NPS units included in this study.*

Discussion

Conceptual Justification

The research team's recommendations focus on the re-establishment of natural disturbance regimes. This entails an active management program in which disturbances, such as fire and grazing, are used to create diverse patches on the landscape.

There must be diversity in areas of disturbance, but there must also be diversity in those areas from year to year. By creating a mosaic on the landscape of different patches, the ecosystem as a whole will be better adapted to evolve, change, and grow with varying threats to the Great Plains. As described above, patch burn grazing is one way to create heterogeneity. Burning different areas each year creates burned and unburned areas which offer diverse benefits to the ecosystem. Newly burned areas are beneficial for forage quality and wildlife habitat. Unburned areas maintain grass availability in case of drought.

Management techniques to achieve heterogeneity are briefly discussed in both fire management plans and native grazer management plans in some units.

Key Uncertainties and Data Gaps

According to Driscoll et al, there are three areas of required knowledge when looking at ecologically sustainable management and in particular in terms of fire management which is a key management practice of grassland ecosystem management (Driscoll *et al.* 2010). The three areas that must be looked into are:

1. Species response to fire regimes
2. Knowledge of how spatial and temporal characteristics of a fire affect biota

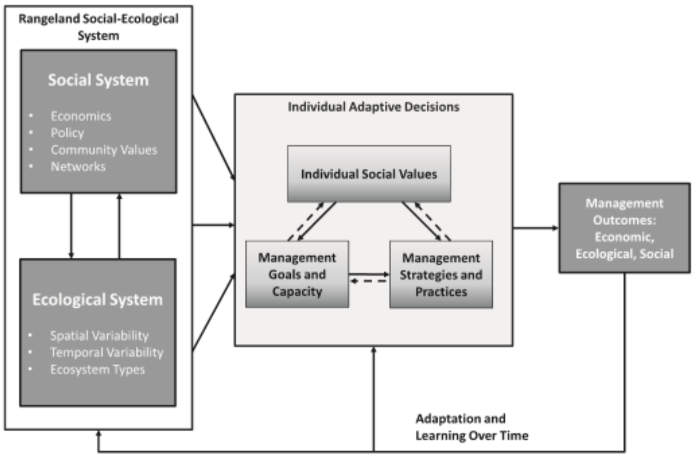

Figure 2: *Adaptive management decision-making framework from Lubell* et al. *(2013).*

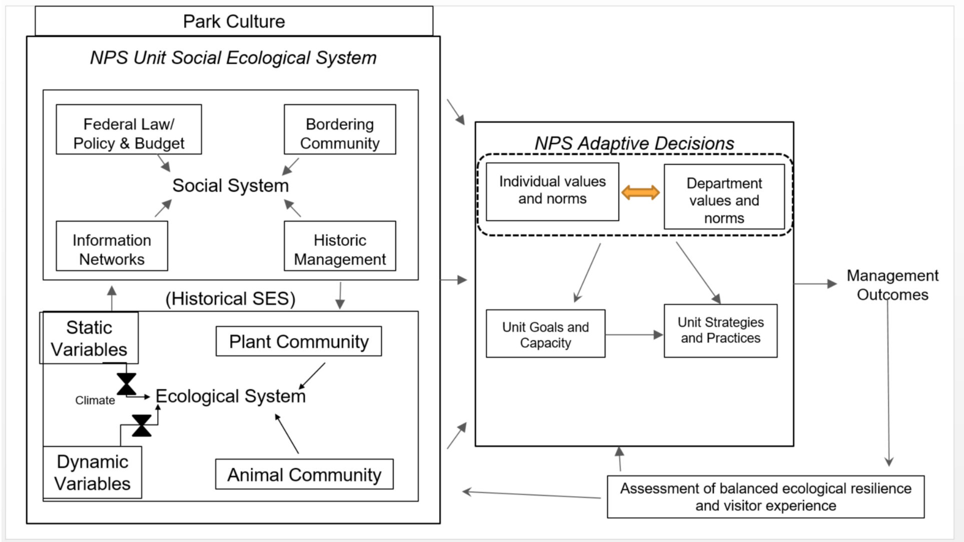

Figure 3: *An NPS-specific framework for adaptive management modified from the adaptive rangeland management decision-making framework by Lubell* et al. *(2013, see fig. 2).*

3. How fire regimes interact with other ecological processes

According to a manager survey, most parks in the Great Plains are managed from a species perspective. For this reason, there is lots of data collected both at most unit levels as well as at a region level within the units. The first point made by Driscoll is to better understand the system by considering all species and their response to a disturbance. This is incorporating each species into a larger framework of management.

Species response to fire regimes. Things that should be looked at are species dependence on specific habitat resources, spatial distribution of fire and how this influences the availability of limiting resources, development of functional groups (also plays into resilience of a SYSTEM vs resilience of a SPECIES), thresholds of fire behavior, and testing of the predictions. Particularly in the face of maintaining ecosystem resilience with changing climactic factors in the region, it will be important to understand how different species respond to fire regimes across their range. It is also very important to understand how fire regimes affect the establishment and spatial arrangement of different species. One example of this is understanding how invasive species emerge and establish post fire and if spatial variability of fire can influence this cycle to minimize the establishment of new populations of invasive species.

Knowledge of spatial and temporal effects

of fire. There are three key pieces to define when establishing a patch burn grazing system on a landscape. These include: the stocking rate, the fire return interval and the season of burning. This is where further research on the beneficial nature of a variety of different combinations would be beneficial. Shorter fire return intervals are beneficial for wetter areas while longer fire return intervals benefit drier climates. The importance of site specific data cannot be overstated. There have been few studies conducted in the northern Great Plains but those that have been conducted have been beneficial in showing that fire does not negatively impact this ecosystem (Vermeire *et al.* 2011). The fact that this study displayed the importance of fire, this supports the recommendation of providing resources to reinvigorate this disturbance regime.

Interaction of fire regimes and other processes. Fire is overall, the most intense form of disturbance on grasslands and also the piece that needs the most direct and constant management while it is affecting the landscape. Once the season of fire, the spatial extent of fire and the intensity of fire is determined for the most positive effects on the landscape in question, then you can begin to add to this disturbance to exacerbate benefits to the ecosystem. We advise looking at how grazing processes interact with fire. This takes an understanding of how large your patch sizes created by fire will be and then how many animals those patches can stand. Based on how many animals your landscape contains may also cause you to revise the fire regime you have established. The interaction will take constant adjustment to create a regime to achieve unit specific goals. Unit specific data and research studies to determine the capacity of your landscape for disturbance will be intensive at the outset, but once initial data has been collected to establish a regime, the natural processes should carry out ecosystem functioning and eventually require less constant human control.

Looking at both sides of interactions, the disturbance regime affects the landscape, but factors of the landscape or factors created on the landscape also impact the regime. For example, grazing management and invasive species can alter fuel load and constrain burn season. Understanding the effects that management practices create for the disturbance regime is always something to be cognizant of.

Implications for Management

Our recommendations include focusing prescribed fire and grazing on pre-determined patches within NPS units. We also recommend focusing on a system perspective and creating management plans that incorporate several aspects of the ecosystem rather than writing one plan per species. Thinking in this systems perspective will slowly change the goals of NPS management from species vitality to ecosystem processes vitality. If we want to maintain ecosystems as they are and "unimpaired for future generations", the processes that make grasslands what they are should demand the most attention. Functional groups of species can perform similar functions in an ecosystem. As long as a required function is performed, less pressure needs to be placed on what specific species is performing that function. By taking this mind frame, less pressure will be placed on budgets and personnel to maintain unrealistic expectations for grassland ecosystems into the future.

Following along with the three pieces of information previously mentioned, we specifically recommend, region-wide, to "continue to research the response of specific target species response to fire and specifically prescribed fire in different seasons" (Driscoll *et al.* 2010).

Specific studies to focus on and data to collect would be

- Spatial and Temporal Characteristics of Fire and How that Affects Biota
- How Fire Affects Ecosystem Processes

Disturbance regimes are essential processes for native grasslands of the Midwest region. By acknowledging this fact and focusing management on the establishment of this disturbance regime could ultimately lead to less management inputs in the year. Instilling a disturbance regime creates native heterogeneity across the protected landscape. Heterogeneity implies diversity of the landscape and all things that depend on or makeup that landscape. When diversity is present, an ecosystem is best prepared to absorb shocks and pressures (Walker & Salt 2012). Shocks and pressures are inherent parts of managing a protected area in a surrounding landscape of utilitarian focus. A resilient landscape will influence the amount of management time and budget required to maintain essential processes. When the landscape is thought of as a system, and that system is poised to rebound, it can be more so left to its own devices with the trust that instilling nature regimes will beget natural processes going forward.

In conclusion, we suggest coupling disturbances into a disturbance regime. Two native disturbances on grasslands that align and benefit one another are fire and grazing. This has been implemented on one grassland unit in the region with native herbivores in a technique called patch-burn grazing. This technique is a way to encourage pyric herbivory on the landscape. As this has been seen to benefit the landscape at TAPR, we suggest translating this technique to other units. In order to translate and set up this process in new locations, plant productivity is required to prescribe the preferred stocking rate and spatial extent of the patches created by patch- burn grazing. New data will need to be collected through grassland exclosures and weighing of vegetative material.

References cited

1. Allred, B. W., Fuhlendorf, S. D. & Hamilton, R. G. The Role of Herbivores in Great Plains Conservation: Comparative Ecology of Bison and Cattle. *Ecosphere* **2,** art26 (2011).
2. Anderson, R. H., Fuhlendorf, S. D. & Engle, D. M. Soil nitrogen availability in tallgrass prairie under the fire–grazing interaction. *Rangeland Ecology & Management* **59,** 625–631 (2006).
3. Bachelet, D., Lenihan, J. M., Daly, C. & Neilson, R. P. Interactions between Fire, Grazing and Climate Change at Wind Cave National Park, SD. *Ecological Modelling* **134,** 229–244 (2000).
4. Bestelmeyer, B. T. & Briske, D. D. Grand Challenges for Resilience-Based Management of Rangelands. *Rangeland Ecology & Management* **65,** 654–663 (2012).
5. Briggs, J. M., Knapp, A. K., *et al.* An Ecosystem in Transition: Causes and Consequences of the Conversion of Mesic Grassland to Shrubland. *BioScience* **55,** 243–254 (2005).
6. Churchwell, R. T., Davis, C. A., Fuhlendorf, S. D. & Engle, D. M. Effects of patch-burn management on Dickcissel nest success in a tallgrass prairie. *The Journal of Wildlife Management* **72,** 1596–1604 (2008).
7. Cole, D. N. & Yung, L. *Beyond naturalness: rethinking park and wilderness stewardship in an era of rapid change* (Island Press, 2012).
8. Coppedge, B. R., Fuhlendorf, S. D., Harrell, W. C. & Engle, D. M. Avian community response to vegetation and structural features in grasslands managed with fire and grazing. *Biological Conservation* **141,** 1196–1203 (2008).
9. Creswell, J. *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* [Online; accessed 2016-04-10] (Sage Publications, Thousand Oaks, California, 2003).
10. Driscoll, D. A., Lindenmayer, D. B., *et al.* Fire management for biodiversity conservation: Key research questions and our capacity to answer them. *Biological Conservation* **143,** 1928–1939 (2010).
11. Fuhlendorf, S. D. & Engle, D. M. Application of the fire–grazing interaction to restore a shifting mosaic on tallgrass prairie. *Journal of Applied Ecology* **41,** 604–614 (2004).
12. Fuhlendorf, S. D., Engle, D. M., Elmore, R. D., Limb, R. F. & Bidwell, T. G. Conservation of Pattern and Process: Developing an Alternative Paradigm of Rangeland Management. *Rangeland Ecology & Management* **65,** 579–589 (2012).
13. Fuhlendorf, S. D., Fynn, R. W. S., McGranahan, D. A. & Twidwell, D. In *Rangeland Systems* 169–196 (Springer, Cham, 2017).
14. Gitzen, R., Wilson, M., *et al. Northern Great Plains Network Vital Signs Monitoring Plan* tech. rep. (2010).
15. Hobbs, R. J. & Huenneke, L. F. Disturbance, Diversity, and Invasion: Implications for Conservation. *Conservation Biology* **6,** 324–337 (1992).
16. Holling, C. S. & Meffe, G. K. Command and Control and the Pathology of Natural Resource Management. *Conservation Biology* **10,** 328–337 (1996).
17. Hovick, T. J., Elmore, R. D. & Fuhlendorf, S. D. Structural heterogeneity increases diversity of non-breeding grassland birds. *Ecosphere* **5,** 1–13 (2014).
18. Huang, R. *RQDA: R- based Qualitative Data Analysis* (2018).
19. Larkin, D. J., Bruland, G. L. & Zedler, J. B. In *Foundations of Restoration Ecology* (eds Palmer, M. A., Zedler, J. B. & Falk, D. A.) 271–300 (Island Press/Center for Resource Economics, Washington, DC, 2016).
20. Lawes, M. J., Midgley, J. J. & Clarke, P. J. Costs and benefits of relative bark thickness in relation to fire damage: a savanna/forest contrast. *Journal of Ecology* **101,** 517–524 (2013).

21. Lebel, L., Anderies, J. M., *et al.* Governance and the Capacity to Manage Resilience in Regional Social-Ecological Systems. *Ecology and Society* **11** (2006).
22. Lubell, M. N., Cutts, B. B., *et al.* Conservation Program Participation and Adaptive Rangeland Decision-Making. *Rangeland Ecology & Management* **66,** 609–620 (2013).
23. McGranahan, D. A., Engle, D. M., Fuhlendorf, S. D., Miller, J. R. & Debinski, D. M. An invasive cool-season grass complicates prescribed fire management in a native warm-season grassland. *Natural Areas Journal* **32,** 208–214 (2012).
24. McGranahan, D. A., Engle, D. M., Miller, J. R. & Debinski, D. M. An invasive grass increases live fuel proportion and reduces fire spread in a simulated grassland. *Ecosystems* **16,** 158–169 (2013).
25. McGranahan, D. A., Henderson, C. B., *et al.* Patch burning improves forage quality and creates grass-bank in old-field pasture: results of a demonstration trial. *Southeastern naturalist* **13,** 200–207 (2014).
26. Midgley, J. J., Sawe, T., Abanyam, P., Hintsa, K. & Gacheru, P. Spinescent East African savannah acacias also have thick bark, suggesting they evolved under both an intense fire and herbivory regime. *African Journal of Ecology* **54,** 118–120 (2016).
27. Montello, D. & Sutton, P. *An introduction to scientific research methods in geography and environmental studies* (Sage, 2012).
28. Moranz, R. A., Debinski, D. M., McGranahan, D. A., Engle, D. M. & Miller, J. R. Untangling the effects of fire, grazing, and land-use legacies on grassland butterfly communities. *Biodiversity and Conservation* **21,** 2719–2746 (2012).
29. Peterson, G., Allen, C. R. & Holling, C. S. Ecological Resilience, Biodiversity, and Scale. *Ecosystems* **1,** 6–18 (1998).
30. R Core Team. *R: A Language and Environment for Statistical Computing* version 3.3.3. Vienna, Austria: R Foundation for Statistical Computing, 2017.
31. Ricketts, A. M. & Sandercock, B. K. Patch-burn grazing increases habitat heterogeneity and biodiversity of small mammals in managed rangelands. *Ecosphere* **7** (2016).
32. Russell, M. L., Vermeire, L. T., Ganguli, A. C. & Hendrickson, J. R. Season of fire manipulates bud bank dynamics in northern mixed-grass prairie. *Plant ecology* **216,** 835–846 (2015).
33. Samson, F. B., Knopf, F. L. & Ostlie, W. R. Great Plains Ecosystems: Past, Present, and Future. *Wildlife Society Bulletin* **32,** 6–15 (2004).
34. Spaak, J. L. *Riparian area invasive plant management along the Niobrara River, targeting yellow flag iris (Iris pseudacorus L.)* PhD thesis (2016).
35. Stroppel, D. J. *Evaluation of patch-burn grazing on species richness and density of grassland birds* [Online; accessed 2018-09-11]. PhD thesis (2009).
36. Svedarsky, W. D., Toepfer, J., Westemeier, R. & Robel, R. *Effects of management practices on grassland birds: Greater Prairie-Chicken* tech. rep. [Online; accessed 2018-09-10] (Jamestown, ND, 2003).
37. Thomas, J. W. Forest Service perspective on ecosystem management. *Ecological Applications* **6,** 703–705 (1996).
38. Turner, M. G. Landscape Ecology: The Effect of Pattern on Process. *Annual Review of Ecology and Systematics* **20,** 171–197 (1989).
39. Twidwell, D., Rogers, W. E., *et al.* The rising Great Plains fire campaign: citizens' response to woody plant encroachment. *Frontiers in Ecology and the Environment* **11** (2013).
40. Umbanhowar Jr, C. E. Recent fire history of the northern Great Plains. *American Midland Naturalist,* 115–121 (1996).

41. Vermeire, L. T., Crowder, J. L. & Wester, D. B. Plant Community and Soil Environment Response to Summer Fire in the Northern Great Plains. *Rangeland Ecology & Management* **64,** 37–46 (2011).

42. Walker, B. & Salt, D. *Resilience thinking: sustaining ecosystems and people in a changing world* [Online; accessed 2016-12-08] (Island Press, 2012).

43. Wiens, J. A. In *The Ecological Basis of Conservation* 93–107 (Springer, Boston, MA, 1997).

Appendix A. Agate Fossil Beds National Monument

Current Grassland Management Goals and Programs

Grassland Management Goals

The majority of management goals within Agate Fossil Beds National Monument (AGFO) pertain to cultural resources management. The Foundational Document and Resource Management Plan, focus on cultural resource management and interpretation. Natural resources are not a fundamental resource of value (FRV) for AGFO, nor are they mentioned to any specifics in the enabling legislation of the unit. Interviews conducted at AGFO stated the focus on cultural resources and simply managing the prairie because it is included within the NPS property they protect. The only goals were to maintain the prairie so that the landscape could mimic what the area looked like when Red Cloud and James Cook were present, and strive for invasive species eradication.

Grassland Management Programs

There are no continuous natural resource management efforts conducted by unit staff as there are no natural resource staff stationed at the monument.

Management Plans and Data Available

Management Plans

Title	Year
Interpretive Plan	2011
Foundation Document	2012
Bison Reintroduction Feasibility	2014
Natural Resource Condition Assessment	2018

Table A.1: *Management documents for AGFO published from 2008-2018*

The Foundational Document, written in 2012, describes the prairie as an “other important resource”. The Foundational Document states that the “shortgrass prairie and the Niobrara riparian ecotone are regionally important parts of the high plains ecosystem.” It gives no further ecological details. Management plans published in the last ten years are listed in Table A.1. The most recent, the Natural Resource Condition Assessment, was a useful resource in the completion of this report. The Foundation Statement was also beneficial as it laid out the goals and the main reasons for establishment of the monument. There are more management plans written, but they are over ten years old. Effective adaptive management will likely require these older plans to be revisited and perhaps revised, particularly the 2001 fire management plan.

Data Available

Interviews expressed not much data is used or thought to exist at AGFO. Monument staff interact with Northern Great Plains I&M network professionals. It was stated several times that they rely on I&M staff or other regional professional staff to alert to AGFO natural resource issues that arise. AGFO moved from the Heartland Monitoring Network to the Northern Great Plains Monitoring Network. This is the reason for two data sets of monitoring data.

Title of Data	Type of Data	Spatial Extent
Climate Change Exposure	Climate	weather at the park un

Title of Data	Type of Data	Spatial Extent
Geologic Resources Inventory Report	Geology	park wide
Plant Community Composition	Vegetation	Unit wide
Plant Community Monitoring	Vegetation	11 monitoring sites est
Riparian Invasive Plant	Vegetation	48 2x2m plots in high y
Groundwater Monitoring	Water	three wells within the u
Nebraska Stream Biological Monitoring Program	Water	Niobrara River
Fish Inventory	Wildlife	2,000m of Niobrara riv
Aquatic Invertebrate Community	Wildlife	3 locations separated b
Aquatic Invertebrates	Wildlife	Three sampling points
Landbird Monitoring	Wildlife	96 points surveyed acr
Acoustic Bat Surveys	Wildlife	43 stations across the
Fish of the Niobrara River	Wildlife	8 locations within mon
Status of Native Stream Fishes in Protected Areas of the Niobrara River	Wildlife	Niobrara river within A
2010 Field Season Report Bird Monitoring at AGFO	Wildlife	40 points across the m

Disturbance Regimes

Grazing

Heavy levels of livestock grazing were present on monument lands from the late 1880's until monument authorization in 1965. Removal of grazing allows fuel loads to build up causing AGFO to be of high danger for extreme fire behavior. The Department of Interior initiative, "Back Home on the Range", communicated the importance of establishing native herbivores, and particularly bison herds, within NPS units in the Great Plains (Hardy & Plumb, 2016). AGFO was selected as a possible unit for reintroduction. Due to surrounding land management, Monument staff seem to be more open to a livestock grazing program than bison grazing.

Fire

The 2001 Fire Management NEPA EA states, "Park lands have not been grazed, burned (except for a few acres in a research project), or mowed (other than maintenance and thistle control) since the park's authorization." Since 2001, there has been some fire to create a burned mosaic on the landscape (Fig. A.2). There are five burn units across the monument (Fig. A.1). Since 1992, there have been eight prescribed fires and two wildfires covering 1,907 acres.

Data gaps and suggested research

Data Gaps

Written documentation of landscape ecosystem goals would highly benefit the managers at AGFO. With little staff and scant funds to apply to natural resource management, having the most information available would allow them to best assign the resources they are allotted for the highest impact. Overall, there are data available from I&M on vegetation and wildlife as well as extensive information on water quality and other aquatic resources. Using the data to implement some kind of management is the missing piece for AGFO. Although, as the landscape has not been disturbed significantly in recent years, the vegetative response to disturbance is a key data gap. Productivity data as well as erosion data is missing in terms of understanding the effect of a large grazer. Livestock impact on the Niobrara River would be beneficial ahead of establishing a grazing disturbance.

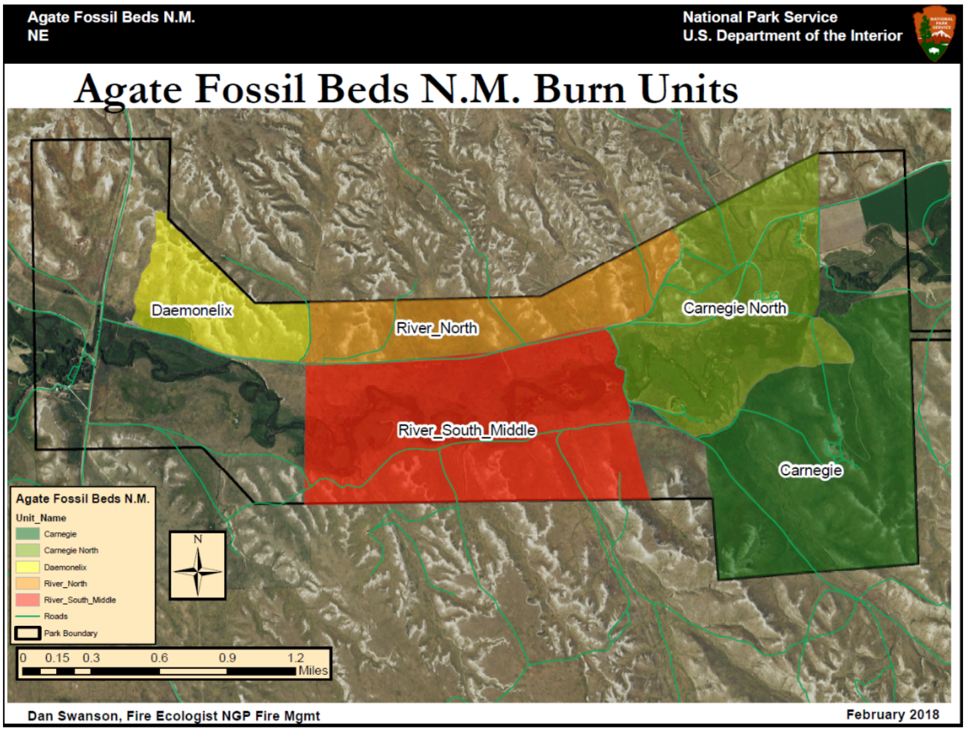

Figure A.1: *Burn units of AGFO*

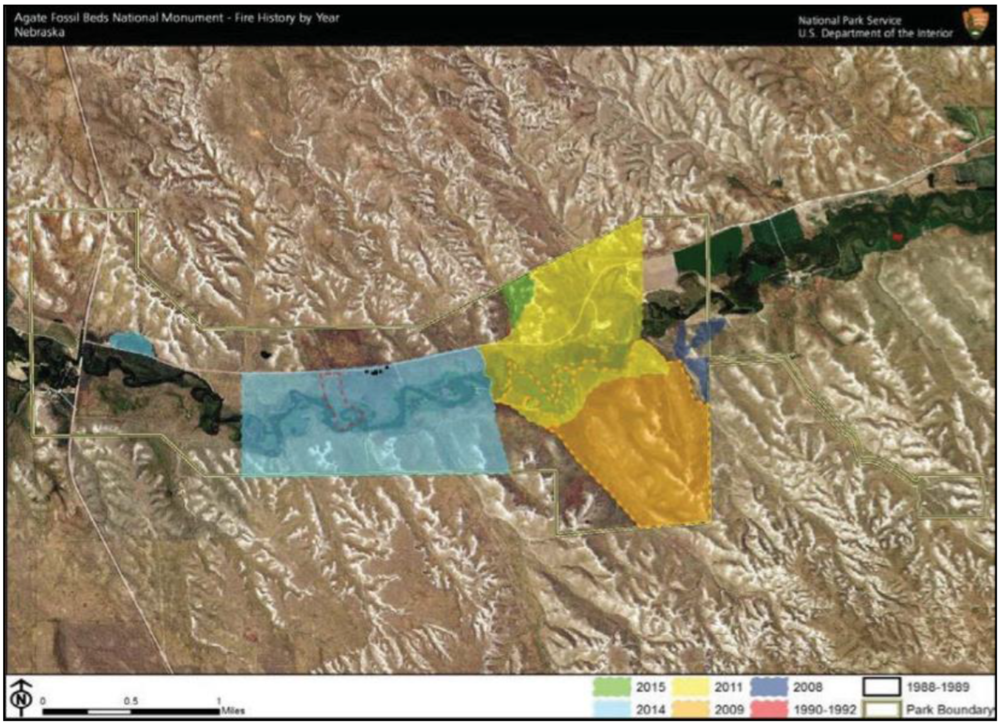

Figure 4.8.11. Map of recent fire history at Agate Fossil Beds National Monument (NPS) (Ashton and Davis 2016).

Figure A.2: *Mosaic created through periodic burning at AGFO.*

Suggested Research

Of particular note was that during the interviews, Monument staff believe that a large grazer such as cattle may help to diminish their largest invasive species problem: the yellow flag iris. Repeated trampling by a large grazer seems to lessen populations of the invasive iris on surrounding lands (2016 Jordan Spark Study). There should be further research of grazing impacts on the AGFO prairie.

Management Recommendations: Establish a grazer on the landscape

With the significant lack of natural resources staff and a natural resources management program (and the goal of filling cultural positions ahead of natural resource positions), it would seem easier to enact a livestock grazing program than a bison grazing program. Although bison are the NPS preferred alternative, cattle can accomplish a similar goal with significantly less budgetary and staff input. To accomplish this, they may take suggestions from Tallgrass Prairie National Preserve who leases a pasture of their land to local cattle owners to manage the prairie to the most conservative AUM and seasonality of cattle grazing. Cattle would also accomplish the cultural focus of the Monument in wanting to restore the prairie to what it looked like when James Cook and Red Cloud were living in the area. Revenue from cattle grazing fees could be used to support cultural resource management. A focus would be put on restoring a grazer to the ecosystem while also increasing budgetary support to the true meaning of the Monument: cultural preservation.

Once the large grazer were established, fire should be more present on the landscape. It will aid in the movement of cattle across the unit. It is our recommendation that a coupled disturbance regime be established to increase heterogeneity of the grassland. Very little disturbance is currently present on the landscape. Introducing a coupled disturbance regime would benefit the wildlife that depend on this patch of habitat for their vitality.