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Natural Resources Condition Assessment, Agate Fossil Beds National Monument (February 2020 Revision)

Reilly R. Dibner
University of Wyoming

Nicole Korfanta
University of Wyoming

Gary Beauvais
University of Wyoming

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National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Natural Resource Condition Assessment

Agate Fossil Beds National Monument (February 2020 Revision)

Natural Resource Report NPS/AGFO/NRR—2020/2074

ON THE COVER
Agate Fossil Beds National Monument
Photography by: Zachary Frank, Shutterstock

Natural Resource Condition Assessment

Agate Fossil Beds National Monument
(February 2020 Revision)

Natural Resource Report NPS/AGFO/NRR—2020/2074

Authors: Reilly R. Dibner[1], Nicole Korfanta[1], Gary Beauvais[2]

Resource Section Authors: Jonathan Bowler[1] (Viewshed, Night Sky), Reilly R. Dibner (Viewshed, Night Sky, Soundscape [adapted from NPS language], Air Quality, Surface Water Quality, Fish, Pollinators), Kit Freedman[1] (Introduction and Resource Setting), Kelli C. Trujillo[1] (Geology, Paleontological Resources), Victoria H. Zero[1] (Birds, Fish)

Design: Jessica Perry[3]

[1]William D. Ruckelshaus Institute of Environment and Natural Resources
University of Wyoming
Laramie, Wyoming

[2]Wyoming Natural Diversity Database
University of Wyoming
Laramie, Wyoming

[3]Creative Blue Yonder
Laramie, Wyoming

February 2020

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received informal peer review, which was provided by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data. The level and extent of peer review was based on the importance of report content or its potentially controversial or precedent-setting nature.

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Executive Summary

In collaboration with the National Park Service, the University of Wyoming Ruckelshaus Institute of Environment and Natural Resources and the Wyoming Natural Diversity Database completed the Natural Resource Condition Assessment (NRCA) for Agate Fossil Beds National Monument (NM). The purpose of the NRCA is to provide park leaders and resource managers with information on resource conditions to support near-term planning and management, long-term strategic planning, and effective science communication to decision-makers and the public.

Agate Fossil Beds NM was authorized in 1965 and established in 1997. The purposes of the park include protecting the paleontological resources on the site and providing a center for paleontological research and fossil display; protecting, curating, and exhibiting the James H. Cook Red Cloud Native American collection; protecting and revealing the intersection between culture, landscape, and science; and preserving the short-grass prairie and Niobrara riparian ecosystems.

The assessment for Agate Fossil Beds NM began in 2015 with a facilitated discussion among park leadership and natural resource managers to identify high-priority natural resources and existing data with which to assess condition of those resources. Data were synthesized to evaluate each resource according to condition, trend in the condition, and confidence in the assessment. Natural resource conditions were the basis for a discussion with park leadership and natural resource managers, who then identified critical data gaps and management issues specific to Agate Fossil Beds NM. Resource experts, park staff, and network personnel reviewed this assessment.

Priority natural resources were grouped into three categories: Landscape Condition Context, Supporting Environment, and Biological Integrity.

The resources categorized as Landscape Condition Context included viewshed, night sky, and soundscape. At the time of this assessment, these resources were all in good condition.

Supporting Environment—or physical environment—resources included air quality, surface water quality, geology, and paleontological resources. Air quality, surface water quality, and geology were of moderate concern; the condition of paleontological resources was not available due to a lack of data on poaching and vandalism of fossils.

The natural resources that composed the Biological Integrity category included vegetation, birds, fish, and pollinators. Vegetation and pollinators resources were of moderate concern, fish condition had deteriorated substantially since the late 1980s and warranted significant concern. We were unable to assign a condition to birds in the absence of specific management goals.

This assessment includes a general background on the NRCA process (Chapter 1), an introduction to Agate Fossil Beds NM and the natural resources included in the assessment (Chapter 2), a description of methods (Chapter 3), condition assessments for 11 natural resources (Chapter 4), and a summary of findings accompanied by management considerations (Chapter 5).

Acknowledgments

Many individuals contributed to this Natural Resource Condition Assessment. In particular, we thank Kara Paintner-Green, Network Coordinator in the Northern Great Plains Network of the National Park Service (NPS), and Carmen Thomson, Midwest Region Inventory Monitoring Program Manager of the NPS, for their guidance and review throughout the project. Agate Fossil Beds National Monument (NM) personnel, James Hill, Superintendent; Lil Mansfield, Ranger; and Bill Matthews, Maintenance Worker Supervisor, provided site-specific details about natural resources that substantially improved the quality of this assessment. Subject matter experts were critical to this process and provided content review, technical expertise, and guidance on regulatory standards. We extend particular thanks to Mark Meyer (NPS), Emma Brown (NPS), Ksienya Taylor (NPS), Rachel Benton (NPS), Lusha Tronstad (Wyoming Natural Diversity Database), Dave Ihrie (Nebraska Department of Environmental Quality), Pete Penoyer (NPS), Isabel Ashton (NPS), Angela Jarding (NPS), Adam Green (Bird Conservancy of the Rockies), Tim Nuttle (Civil and Environmental Consultants, Inc.), Tim O'Connell (Oklahoma State University), Darren Thornbrugh (NPS), and Brennan Hauk (NPS). Kim Messersmith, University of Wyoming Ruckelshaus Institute of Environment and Natural Resources, managed the financial side of this project, and we thank her for her work. Finally, we thank all other reviewers whose comments contributed to the quality of this assessment.

Prologue

Publisher's Note: This report was first published in 2019, however, an error was noted in the report resulting in this revised version. The scope/nature of the revision includes:

> The sentence "In 2012, a request for assistance with northern pike removal and reintroduction of native fish was denied (Medley 2012)"—included on page 188 of the original report (section 4.10.1 Background and Importance)—has been removed.

Chapter 1. NRCA Background Information

Natural Resource Condition Assessments (NRCAs) evaluate current conditions for a subset of natural resources and resource indicators in national park units, hereafter "parks." NRCAs also report on trends in resource condition (when possible), identify critical data gaps, and characterize a general level of confidence for study findings. The resources and indicators emphasized in a given project depend on the park's resource setting, status of resource stewardship planning and science in identifying high-priority indicators, and availability of data and expertise to assess current conditions for a variety of potential study resources and indicators.

NRCAs Strive to Provide…

- *Credible condition reporting for a subset of important park natural resources and indicators*
- *Useful condition summaries by broader resource categories or topics, and by park areas*

NRCAs represent a relatively new approach to assessing and reporting on park resource conditions. They are meant to complement, not replace, traditional issue-and threat-based resource assessments. As distinguishing characteristics, all NRCAs

- Are multi-disciplinary in scope;[1]
- Employ hierarchical indicator frameworks;[2]
- Identify or develop reference conditions/values for comparison against current conditions;[3]
- Emphasize spatial evaluation of conditions and Geographic Information System (GIS) products;[4]
- Summarize key findings by park areas;[5] and
- Follow national NRCA guidelines and standards for study design and reporting products.

Although the primary objective of NRCAs is to report on current conditions relative to logical forms of reference conditions and values, NRCAs also report on trends, when appropriate (i.e., when the underlying data and methods support such reporting), as well as influences on resource conditions. These influences may include past activities or conditions that provide a helpful context for

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1 The breadth of natural resources and number/type of indicators evaluated will vary by park.

2 Frameworks help guide a multi-disciplinary selection of indicators and subsequent "roll up" and reporting of data for measures ⇨ conditions for indicators ⇨ condition summaries by broader topics and park areas

3 NRCAs must consider ecologically-based reference conditions, must also consider applicable legal and regulatory standards, and can consider other management-specified condition objectives or targets; each study indicator can be evaluated against one or more types of logical reference conditions. Reference values can be expressed in qualitative to quantitative terms, as a single value or range of values; they represent desirable resource conditions or, alternatively, condition states that we wish to avoid or that require a follow-up response (e.g., ecological thresholds or management "triggers").

4 As possible and appropriate, NRCAs describe condition gradients or differences across a park for important natural resources and study indicators through a set of GIS coverages and map products.

5 In addition to reporting on indicator-level conditions, investigators are asked to take a bigger picture (more holistic) view and summarize overall findings and provide suggestions to managers on an area-by-area basis: 1) by park ecosystem/habitat types or watersheds, and 2) for other park areas as requested.

understanding current conditions, and/or present-day threats and stressors that are best interpreted at park, watershed, or landscape scales (though NRCAs do not report on condition status for land areas and natural resources beyond park boundaries). Intensive cause-and-effect analyses of threats and stressors, and development of detailed treatment options, are outside the scope of NRCAs.

Due to their modest funding, relatively quick timeframe for completion, and reliance on existing data and information, NRCAs are not intended to be exhaustive. Their methodology typically involves an informal synthesis of scientific data and information from multiple and diverse sources. Level of rigor and statistical repeatability will vary by resource or indicator, reflecting differences in existing data and knowledge bases across the varied study components.

The credibility of NRCA results is derived from the data, methods, and reference values used in the project work, which are designed to be appropriate for the stated purpose of the project, as well as adequately documented. For each study indicator for which current condition or trend is reported, we will identify critical data gaps and describe the level of confidence in at least qualitative terms. Involvement of park staff and National Park Service (NPS) subject-matter experts at critical points during the project timeline is also important. These staff will be asked to assist with the selection of study indicators; recommend data sets, methods, and reference conditions and values; and help provide a multi-disciplinary review of draft study findings and products.

NRCAs can yield new insights about current park resource conditions, but, in many cases, their greatest value may be the development of useful documentation regarding known or suspected resource conditions within parks. Reporting products can help park managers as they think about near-term workload priorities, frame data and study needs for important park resources, and communicate messages about current park resource conditions to various audiences. A successful NRCA delivers science-based information that is both credible and has practical uses for a variety of park decision making, planning, and partnership activities.

Important NRCA Success Factors

- *Obtaining good input from park staff and other NPS subject-matter experts at critical points in the project timeline*
- *Using study frameworks that accommodate meaningful condition reporting at multiple levels (measures ➪ indicators ➪ broader resource topics and park areas)*
- *Building credibility by clearly documenting the data and methods used, critical data gaps, and level of confidence for indicator-level condition findings*

However, it is important to note that NRCAs do not establish management targets for study indicators. That process must occur through park planning and management activities. What an NRCA can do is deliver science-based information that will assist park managers in their ongoing, long-term efforts to describe and quantify a park's desired resource conditions and management targets. In the near term, NRCA findings assist strategic park resource planning[6] and help parks to report on government accountability measures.[7] In addition, although in-depth analysis of the effects of climate change on park natural resources is outside the scope of NRCAs, the condition analyses and data sets developed for NRCAs will be useful for park-level climate-change studies and planning efforts.

NRCAs also provide a useful complement to rigorous NPS science support programs, such as the NPS Natural Resources Inventory & Monitoring (I&M) Program.[8] For example, NRCAs can provide current condition estimates and help establish reference conditions, or baseline values, for some of a park's vital signs monitoring indicators. They can also draw upon non-NPS data to help evaluate current conditions for those same vital signs. In some cases, I&M data sets are incorporated into NRCA analyses and reporting products.

NRCA Reporting Products…

Provide a credible, snapshot-in-time evaluation for a subset of important park natural resources and indicators, to help park managers:

- *Direct limited staff and funding resources to park areas and natural resources that represent high need and/or high opportunity situations* ***(near-term operational planning and management)***
- *Improve understanding and quantification for desired conditions for the park's "fundamental" and "other important" natural resources and values* ***(longer-term strategic planning)***
- *Communicate succinct messages regarding current resource conditions to government program managers, to Congress, and to the general public* ***("resource condition status" reporting)***

Over the next several years, the NPS plans to fund an NRCA project for each of the approximately 270 parks served by the NPS I&M Program. For more information visit the NRCA Program website.

[6] An NRCA can be useful during the development of a park's Resource Stewardship Strategy (RSS) and can also be tailored to act as a post-RSS project.

[7] While accountability reporting measures are subject to change, the spatial and reference-based condition data provided by NRCAs will be useful for most forms of "resource condition status" reporting as may be required by the NPS, the Department of the Interior, or the Office of Management and Budget.

[8] The I&M program consists of 32 networks nationwide that are implementing "vital signs" monitoring in order to assess the condition of park ecosystems and develop a stronger scientific basis for stewardship and management of natural resources across the National Park System. "Vital signs" are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values.

Chapter 2. Introduction and Resource Setting

2.1. Introduction

2.1.1. Enabling Legislation

Agate Fossil Beds National Monument (NM) was authorized on June 5, 1965, and established on June 14, 1997 (Public Law 89–33). The purpose of the Monument is:

- To protect the Miocene fossils and associated quarries and related geological phenomena;
- To provide a center for continuing paleontological research and for the display and interpretation of Miocene Epoch fossils;
- To curate, exhibit, and protect the James H. Cook-Red Cloud Native American collection;
- To protect the cultural landscape and to reveal the interaction between cultures, landscapes, and science, especially the early reservation/pioneer ranching period;
- To preserve the short-grass prairie and the Niobrara riparian ecotone as a regionally important part of the high plains ecosystem (NPS 2008).

Agate Fossil Beds National Monument near Harrison, Nebraska (Photo by CyberXRef, Wikipedia).

2.1.2. Geographic Setting

Agate Fossil Beds National Monument is located in the Niobrara River Valley of western Nebraska. The Monument contains 11,617 acres and preserves a unique area of the High Plains. It is located 65 miles east-southeast of its headwaters in the Hat Creek Breaks of eastern Wyoming. Wetlands stretch out from the river and meet terraces that lead to the break and buttes. The buttes contain important information about the life of mammals in the Miocene era, some 20 million years ago (NPS 2016a).

2.1.3. Visitation Statistics

Visitation data for Agate Fossil Beds NM are available for 1979–2015. The total number of visitors ranged from 8,115 in 1979 to 20,596 in 1997, with an average of 12,380 visitors, annually. The number of recreational visitors in 2015 was 13,264. Visitation data by month are available for the same period of time. Although there has been monthly variation by year, the months receiving the greatest number of average visitors over the recording period were June through September (NPS 2016b).

2.2. Natural Resources

A summary of the natural resources at Agate Fossil Beds NM is presented in this section and includes information known prior to the completion of this condition assessment. Resource sections include: Viewshed, Night Sky, Soundscape, Air Quality, Surface Water Quality, Geology, Paleontological Resources, Vegetation, Birds, Fish, and Pollinators.

2.2.1. Ecological Units and Watersheds

Agate Fossil Beds NM is located in Northwestern Mixed Grasslands ecoregion of the Northern Great Plains, distinguished from other grassland types by the harsh winter climate; short growing seasons; periodic, severe droughts; and vegetation. The largest grassland ecoregion in North America, this biologically-important area is under threat from habitat alteration for wheat production, invasive and exotic species, and increased industrial activity (Ricketts 1999).

2.2.2. Resource Descriptions

In this section we have summarized background information about key natural resources at Agate Fossil Beds NM. The assessment does not include all important resources present in the park, but focuses instead on particularly high priority resources as identified by park staff.

The descriptions included here are direct excerpts from the resource assessment sections in Chapter 4 of this NRCA. We have included these introductions to each resource verbatim, but have removed the literature citations for readability. Please refer to the full resource sections for appropriate literature citations and acknowledgment of intellectual property.

Viewshed

The NPS prioritizes conserving scenery for the enjoyment of visitors and current and future generations. Scenic park resources are protected from impairment, which is any change that harms the integrity of the park unit. NPS encourages park units to protect the iconic and spectacular scenery of the national parks by preserving visual resources. Protecting park viewsheds, the geographic area visible from a given location, is key to this goal. The viewshed within a park unit is the visible area from all locations within the park.

Exposed fossils, cultural landscapes, the Niobrara River, and views of western Nebraska are an important part of the visitor experience at Agate Fossil Beds NM. The landscapes in and around the park offer visitors an opportunity to enjoy a visual setting dominated by a largely intact and unaltered mixed grass prairie.

Night Sky

Spectacular starry skies and dark nights are highlights of national parks for anyone who camps out or visits after dusk. The patterns among constellations are essentially the same ones that have been visible to humans for thousands of years.

More than a visual resource, dark skies play an important role in healthy ecosystems. The absence of light is important to nocturnal wildlife, light-sensitive amphibians, reptiles, insects, plants, and migrating birds requiring starry skies for navigation.

Clear, dark night skies are a valuable natural resource at Agate Fossil Beds NM. Stargazing programs are usually conducted in the fall, when the sun begins to set earlier. Rangers at Agate Fossil Beds NM lead these interpretive programs, guiding participants to identify sky objects and operate telescopes.

Soundscape/Acoustic Environment

Visitors to national parks indicate that an important reason for visiting the parks is to enjoy the relative quiet that parks can offer. Sound also plays a critical role in intra- and inter-species communication, including courtship and mating, predation and predator avoidance, and effective use of habitat.

Agate Fossil Beds NM is surrounded by vast areas of prairie, with some agricultural development along the Niobrara River upstream and downstream of the park. Primary sources of non-natural sounds within the park include agricultural activities, automobile traffic on State Highway 29 and River Road, and air traffic passing overhead.

Air Quality

Most visitors expect clean air and clear views in parks. However, air pollution can sometimes affect Agate Fossil Beds NM. Clean, clear air is critical to human health, the health of ecosystems, and the appreciation of scenic views. Pollution can damage animal health (including human health), plants, water quality, and alter soil chemistry. Our ability to clearly see color and detail in distant views can also be impacted by air pollution.

The NPS is dedicated to preserving natural resources, including clear air. The National Park Service Organic Act and the Clean Air Act codify this commitment, specifying that NPS protect air quality within park units for the integrity of other natural and cultural resources.

Water Quality

Surface waters form complex ecosystems that support a vast number of uses. They provide critical wildlife and plant habitat, sources and sinks in water and nutrient cycles, and numerous recreational opportunities. Surface waters are also aesthetic resources and, often, public health resource when they connect to a drinking water supply.

Agate Fossil Beds NM is located in northwest Nebraska on the Niobrara River in the Niobrara River Drainage of the Middle North Platte-Scotts Bluff Watershed, which eventually flows east into the Missouri River. The Niobrara River is a prominent natural feature that bisects the park unit and is an important resource for agriculture, recreation, and plans and wildlife in the region. Downstream of Agate Fossil Beds NM, the largely undisturbed Niobrara River is a designated Nation Scenic River for its unique natural and cultural resources.

Geology

Geological resources underlie and affect many other resources within National Park System units. In Northern Great Plains area where Agate Fossil Beds NM is located, most of the bedrock is composed of soft Upper Cretaceous and Tertiary sediment strata. Many of these rocks are rich in swelling clays, which can make them highly friable and lead to slope instability. Modern river valleys in this region hold thick fluvial gravel deposits that overlie the sedimentary bedrock.

Geological hazards in the northern Great Plains area are mostly related to mass wasting activities, as the soft, clay-rich bedrock is often prone slumps, slides, and rockfalls. While events such as these are natural, various land uses and human activities can affect the magnitude and rate of mass wasting activities. For this reason and because of the potential danger to visitors, NPS places a high priority on managing key locations within the park to minimize uncharacteristic or dangerous mass wasting events. The Great Plains region has not been seismically active for millions of years and earthquakes are uncommon in the area.

Paleontological Resources

The fossil resources at Agate Fossil Beds NM are a key attraction to the site and represent the first major accumulations of terrestrial vertebrate fossils of late Eocene and early Oligocene age discovered in North America.

In the northern Great Plains area, most of the fossiliferous bedrock deposits represent two general time periods and environments: the Late Cretaceous Western Interior Seaway, with remains of invertebrates such as ammonites and vertebrates such as bony fish, sharks, and marine reptiles; and the Tertiary terrestrial deposits of Oligocene and Miocene age that record the spread of grasslands across the region and the rise of large grazing mammals.

The fossil-bearing rock units that crop out in Agate Fossil Beds NM contain abundant vertebrate fossils indicative of grasslands including: birds; perissodactyls such as rhinoceros, tapirs, and horses; artiodactyls such as camels, oreodonts, and entelodonts ("hell pigs"); and carnivores such as early canids, bears, and mustelids. In addition, a unique trace fossil is known from Agate Fossil Beds NM: the preserved burrow of the early beaver *Paleocastor*. The burrow itself is termed *Daemonelix*, "Devil's Corkscrew" and was initially thought to be the remnants of a cavity formed by a giant taproot.

Vegetation

During the last century, much of the prairie within the Northern Great Plains has been plowed for cropland, planted with non-natives to maximize livestock production, or otherwise developed, making one of the most threatened ecosystems in the United States.

Agate Fossil Beds NM contains 2,770 acres of native mixed-grass prairie intersected by riparian vegetation along the Niobrara River. Vegetation monitoring began in Agate Fossil Beds NM in 1998 by the Heartland Inventory & Monitoring Program and the Northern Great Plains Fire Ecology Program. In 2010, Agate Fossil Beds NM was incorporated into the NGPN. At this time, vegetation monitoring protocols and plot locations were shifted to better represent the entire monument and to coordinate efforts with the FireEP, and sampling efforts began in 2011. In 2012, the NGPN began monitoring an additional 17 plots within the riparian corridor to assess riparian condition.

Birds

Birds are a critical natural resource that provide an array of ecological, aesthetic, and recreational values. As a species-rich group, they encompass a broad range of habitat requirements, and thus may serve as indicators of landscape health. Bird communities can reflect changes in habitat, climate, ecological interactions, and other factors of concern in ecological systems.

Agate Fossil Beds NM is located within the shortgrass prairie bird conservation region. The shortgrass prairie is an arid region with limited vegetation height and diversity. Some of North America's highest priority birds breed here, including the grasshopper sparrow.

Fish

Prairie streams and rivers in the Great Plains are at a great risk to loss and alteration. The Niobrara River in Nebraska has changed in flow regime as a result of damming, particularly at Box Butte Dam, approximately 40 miles downstream of Agate Fossil Beds NM.

The native fish community at Agate Fossil Beds NM appears to have been largely extirpated in recent decades. In 2012, a request for assistance with northern pike removal and reintroduction of native fish was denied. The latest survey of fish at AGFP detected only one species thought to occur naturally within the park, the white sucker. One native species, the plains topminnow, is found primarily in Nebraska and is declining within Nebraska and throughout its range.

Invertebrate Pollinators

Pollinators, animals that assist in the reproduction of plants, include a diverse group of organisms globally, from invertebrates to reptiles to mammals and birds. The diversity and richness of pollinators have declined since the mid-20th century, and some species have disappeared altogether. This massive decline in pollinator health is attributable to a combination of disease, pesticides, and habitat loss. In North America, the decline in invertebrate pollinators in particular is likely to have extensive consequences for native plants and agriculture.

Invertebrate pollinators in Nebraska include native insects and honey bees, all of which have varying food and habitat needs. Agate Fossil Beds NM is home to a total of 19 confirmed butterfly species, and may be host to even more species. While bumble bees and other invertebrate pollinators are likely present in Agate Fossil Beds NM, local census data are lacking for the park.

2.2.3. Resource Issues Overview

The natural resources found in Agate Fossil Beds NM are central to the founding goals of the park and provide opportunity for outreach and research. Maintaining the health of the natural resources is critical to attracting visitors.

The resources within the park and in the surrounding area have been altered by changes in land use, climate, invasive species, natural disturbances, and natural succession and many of these forces are unlikely to change in the future. In particular, the Niobrara River has been severely altered since the park was founded, and invasive species dominate both the riparian area and the fish community. The fossils at the park also warrant an emphasis, as they are exposed to theft and vandalism.

2.3. Resource Stewardship

2.3.1. Management Directive and Planning Guidance

From the NGPN website of the NPS Inventory & Monitoring program (NPS 2016):

> *The NGPN I&M Program is one of 32 National Park Service I&M Networks across the country established to facilitate collaboration, information sharing, and economies of scale in natural resource monitoring. It is comprised of 13 national park units, each of which contain a rich and varied array of natural and cultural resources.*
>
> *The parks support unique natural resources, including large areas of northern mixed-grass prairie communities, critical river and riparian habitats, large herds of bison, and two of the four longest caves in the world. These parks and their partners are dedicated to understanding and preserving the region's unique resources through science and education.*

2.3.2. Status of Supporting Science

Availability of data, background information, and assessment protocols varied among natural resources. We describe our approach to identifying appropriate methods in Chapter 3 (Study Design and Methods) of this NRCA.

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Chapter 3. Study Methods

3.1. Introduction and Overview

This NRCA was produced by the University of Wyoming Ruckelshaus Institute of Environment and Natural Resources and the Wyoming Natural Diversity Database in collaboration with the National Park Service.

The purpose of the NRCA is to provide natural resource managers and leadership at Agate Fossil Beds NM with information to support management decisions, strategic planning, and effective science communication to decision-makers and the public on resource conditions. To deliver this information, we:

- Used a collaborative approach to tailor analyses to park-specific needs and opportunities;
- Identified the unique biophysical and cultural resources of management interest;
- Identified existing data (and critical data gaps) and available expert knowledge for understanding and assessing park resources;
- Used a spatially explicit analytic approach to evaluate the current conditions of resources, trends in their status, and drivers of change.

The Agate Fossil Hills (NPS photo).

3.2. Project Design and Methods

3.2.1. Project Phases

We used a two-phase process for completing the assessment for Agate Fossil Beds NM. Phase 1 was conducted in close cooperation with the park and involved selecting a framework for the assessment. During this phase we identified key natural resources, data needs and sources, indicators, and measures to use in the assessment. Phase 2 focused on reviewing scientific literature, gathering and analyzing data, summarizing findings, and corresponding with Agate Fossil Beds NM leadership and natural resource managers to incorporate feedback.

To provide a forum for cross-unit idea exchanges and the establishment of a common analytical process at the beginning of the project, we convened an initial planning meeting with representatives from Agate Fossil Beds NM, Fort Laramie NHS, Scotts Bluff NM, and NGPN to start the project.

Phase 1 – Assessment and Planning

During Phase 1 we established communication and identified shared expectations among NPS representatives, UW staff, and key resource experts. Through conference calls, electronic communication, and ultimately a facilitated scoping workshop, we tailored the NRCA structure to the specific needs, resource types, and data availability for Agate Fossil Beds NM.

Specific goals for Phase 1 included:

- Review of existing NRCAs for best practices (UW team)
- Establishing the NPS/UW NRCA teams that guided the process
- Project Scoping Meeting and iterative discussions to:
  - Review the NRCA process and goals generally with UW/NPS team
  - Select the appropriate study framework to guide the NRCA
  - Identify critical, park-specific biophysical resources for assessment
  - Identify the key indicators of resource condition
  - Identify measures to quantify and/or qualify indicators
- Assess data needs, major data sources, and obvious data gaps
- Refine the timeline and specific deliverables
- Assign team member roles in gathering data and reviewing deliverables/products

We agreed that an appropriate framework (Table 3.1) for our purpose was one adapted from the H. John Heinz II Center for Science, Economics, and the Environment (2008). This framework gave us a hierarchical structure to assess natural resource conditions using indicators and their quantitative and qualitative measures, and to identify data gaps and stressors.

Table 3.1. Natural Resource Condition Assessment framework for Agate Fossil Beds NM.

Context	Resource	Indicator	Measure
I. Landscape condition context	Viewshed	Scenic quality	Landscape character integrity
	Viewshed	Scenic quality	Vividness
	Viewshed	Scenic quality	Visual harmony
	Viewshed	Land cover content	Mid-ground % natural cover
	Viewshed	Land cover content	Mid-ground % developed cover
	Viewshed	Land cover content	Mid-ground % agricultural cover
	Night sky	Night sky quality	Bortle Dark-Sky class
	Night sky	Night sky quality	Synthetic Sky Quality Meter (SQM)

Table 3.1 (continued). Natural Resource Condition Assessment framework for Agate Fossil Beds NM.

Context	Resource	Indicator	Measure
I. Landscape condition context (continued)	Night sky	Night sky quality	Sky Quality Index (SQI)
	Night sky	Natural light environment	Anthropogenic Light Ratio (ALR)
	Soundscape	Anthropogenic impact	Mean I_{50} impact
	Soundscape	Anthropogenic impact	Qualitative assessment
II. Supporting environment	Air quality	Visibility	Haze index
	Air quality	Ozone	Human health (ozone concentration)
	Air quality	Ozone	Vegetation health (W126 measure)
	Air quality	Particulate matter	$Pm_{2.5}$
	Air quality	Particulate matter	Pm_{10}
	Air quality	Nitrogen	Wet deposition of nitrogen
	Air quality	Sulfur	Wet deposition of sulfur
	Air quality	Mercury	Wet deposition of mercury
	Air quality	Mercury	Methlymercury rating
	Water quality	Acidity	pH
	Water quality	Dissolved oxygen	mg/l
	Water quality	Specific conductivity	s/m
	Water quality	Temperature	°c
	Water quality	Turbidity	Qualitative aesthetic assessment
	Water quality	Invertebrate assemblage	HBI
	Water quality	Invertebrate assemblage	EPT index
	Water quality	Invertebrate assemblage	% EPT
	Water quality	Invertebrate assemblage	Evenness
	Water quality	Fecal indicator bacteria	*E. coli* concentration
	Geology	Weathering and erosion	Amount of erosion (mm/year)
	Geology	Weathering and erosion	Mass wasting
	Paleontological resources	Fossil loss	Amount of weathering and erosion
	Paleontological resources	Fossil loss	Fossil poaching and vandalism
III. Biological integrity	Vegetation	Upland plant community structure and composition	Native species richness
	Vegetation	Upland plant community structure and composition	Evenness

Table 3.1 (continued). Natural Resource Condition Assessment framework for Agate Fossil Beds NM.

Context	Resource	Indicator	Measure
III. Biological integrity (continued)	Vegetation	Upland plant community structure and composition	Relative cover of exotic species
	Vegetation	Upland plant community structure and composition	Annual brome cover
	Vegetation	Riparian plant community structure and composition	Native species richness
	Vegetation	Riparian plant community structure and composition	Relative cover of exotic species
	Vegetation	Riparian plant community structure and composition	Relative cover of pale yellow iris
	Breeding birds	Species diversity	Species richness
	Breeding birds	Species abundance	Mean density
	Breeding birds	Conservation value	Mean priority ranking
	Fish	Population growth	Growth rate
	Fish	Community composition	Ratio of native to non-native fish species
	Invertebrate pollinators	Diversity	Shannon index
	Invertebrate pollinators	Abundance	Observed visitation rate
	Invertebrate pollinators	Abundance	Mean density in traps
	Invertebrate pollinators	Vulnerable species	Level of conservation concern

Phase 2 – Analysis and Reporting

During Phase 2 we gathered data, conducted quantitative and qualitative analyses, corresponded with subject matter experts, and summarized our findings. We solicited feedback from leadership and mangers at Agate Fossil Beds NM and incorporated their edits and comments. In Chapter 5 we summarize management goals and data gaps, relying heavily on input from park managers and leaders.

Specific goals for Phase 2 were to:

- Gather existing data for analysis
- Review scientific literature and available data for key natural resources identified in the scoping process
- Use selected measures to evaluate the condition of each of the components

- Identify threats and stressors for each component
- Organize natural resource components, reference conditions, and threats/stressors in the study framework
- Summarize key findings for each park unit
- Correspond with park leadership, resource managers, and subject matter experts and incorporate feedback on resource sections

3.2.2. Assessment Methods

To identify the most relevant indicators of resource condition, and the measures of those indicators (Table 3.1), we relied upon to NPS protocol, peer-reviewed scientific literature, state and federal regulations, technical reports, and resource experts. We described key indicators and appropriate measures, even if data were not available for that resource at the time of our assessment, so that our assessment methods could be repeated in the future and improved should data become available. Specific methods for evaluating the conditions of natural resources are described in detail in the relevant sections of Chapter 4.

Data

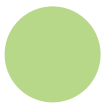
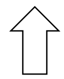
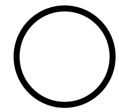
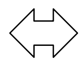
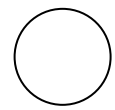
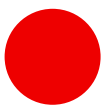
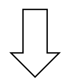
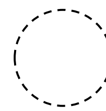
In this assessment we searched for data that were collected within the boundaries of Agate Fossil Beds NM or as near the park to the park as possible. If these data were unavailable, we considered data in the broader region, as acceptable to natural resource managers and leadership at Agate Fossil Beds NM. We used the NPS database, Integrated Resource Management Applications (NPS 2016); other state and federal databases; online databases of scientific literature and technical reports; and consultation with experts to identify the most recent and relevant data for each resource.

Analyses

Condition

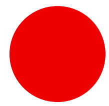
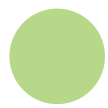
We used quantitative methods when possible and relied upon to the most rigorous assessment methods available, whether quantitative or qualitative. Measures determined the condition category of each indicator, which could be: *Resource in Good Condition*, *Warrants Moderate Concern*, *Warrants Significant Concern*, or *Not Available* (Table 3.2). To select analytical approaches for each measure, and to identify appropriate category value ranges for those measures, we again deferred to NPS protocol, peer-reviewed scientific literature, state and federal regulations, technical reports, and resource experts.

Table 3.2. Symbolism for condition, confidence, and trend.

Condition Status		Trend in Condition		Confidence in Assessment	
Condition Icon	**Condition Icon Definition**	**Trend Icon**	**Trend Icon Definition**	**Confidence Icon**	**Confidence Icon Definition**
	Resource is in Good Condition		Condition is Improving		High
	Resource warrants Moderate Concern		Condition is Unchanging		Medium
	Resource warrants Significant Concern		Condition is Deteriorating		Low
No color	Current Condition is Unknown or Indeterminate	No Arrow	Trend in Condition is Unknown or Not Applicable	–	–

Several resources had only one indicator or a dominant indicator that had the potential to overshadow the other indicators (e.g., an indicator out of federal compliance). For these natural resources, the single or dominant indicator determined the overall condition of the resource. More frequently, multiple indicators determined resource condition. In these cases, we used a quantitative approach to calculate overall resource condition from indicator conditions. We modified an approach developed by the NPS Air Resource Division (NPS-ARD) to assess air quality; this approach uses a point system to assign the indicator to a category (NPS-ARD 2015). Measures that placed the indicator in the *Warrants Significant Concern* category were assigned zero points, *Warrants Moderate Concern* measures were given 50 points, and *Resource in Good Condition* measures were given 100 points. We used the average of these points to assign the indicator to an overall category. The overall condition was *Resource in Good Condition* if the average of these values was between 67 and 100, *Warrants Moderate Concern* between 34 and 66, and *Warrants Significant Concern* between 0 and 33 (Table 3.3).

Table 3.3. Points determining overall indicator condition.

Resource condition		Points for overall condition
Condition Icon Definition	**Condition Icon**	
Warrants significant concern		0 – 33
Warrants moderate concern		34 – 66
Resource in good condition		67 – 100

Confidence

Confidence ratings were based on the quality of available data. We gave a rating of *High* confidence (Table 3.2) when data were collected on site or nearby, data were collected recently, and the data were collected methodically. We assigned a *Medium* confidence rating when data were not collected on site or in close enough proximity to satisfy a *High* rating according to protocol, data were not collected recently, or data collection was not repeatable or methodical. We assigned *Low* confidence when there were no good data sources to support the condition.

We calculated overall confidence—*High*, *Medium*, or *Low*—using a points system similar to overall condition confidence; categories with *High* confidence received 100 points, *Medium* confidence received 50 points, and *Low* confidence received zero points. The overall confidence was *High* if the average of these values was between 67 and 100, *Medium* between 34 and 66, and *Low* between 0 and 33.

Trend

Trend categories were *Improving*, *Unchanging*, *Deteriorating*, or *Not Available* (Table 3.2). To calculate a trend estimate, data requirements varied among resources according to NPS protocol, peer-reviewed scientific literature, state and federal regulations, technical reports, and resource experts. If there were no data available that met these resource-specific requirements for a particular indicator, we indicated that trend was *Not Available* for that indicator.

If trend data were available for all key indicators, we calculated overall trend using a points system (NPS-ARD 2015) to assign an overall trend category of *Improving*, *Unchanging*, or *Deteriorating*. Specifically, we subtracted the number of deteriorating trends from improving trends. If the result of this calculation was three or greater, the overall trend was *Improving*. If the result was negative three or lower, the overall trend was *Deteriorating*. If the result was between negative two and positive two, the overall trend was *Unchanging*. If any measure did not have a trend, then there was no trend for overall condition.

3.3. Literature Cited

National Park Service (NPS). 2016. Integrated Resource Management Applications. https://irma.nps.gov (accessed 30 September 2016).

National Park Service, Air Resources Division (NPS-ARD). 2015. DRAFT National Park Service Air Quality Analysis Methods.

Chapter 4. Natural Resource Conditions

In this chapter we present the natural resource condition assessments. Each of these assessments includes background information about the resource, a discussion of Regional Context, specific methods, and results of the assessment. We used quantitative measures whenever possible and applied qualitative methods when relevant. We describe the indicators and measure of condition for each resource and, at the end of each section, present an overall condition for the resource.

4.1. Viewshed

4.1.1. Background and Importance

In the mid-to-late 19th century, artists who accompanied surveys and expeditions were inspired in their travels to produce paintings that contributed to a romantic vision of western landscapes. The beauty portrayed in their paintings, as well as in photographs captured during surveys and expeditions, promoted national interest in scenic western landscapes and helped to convince the U.S. Congress to create the first national park at Yellowstone in 1872 (Haines 1974, 1996). The aesthetic value associated with this park became a founding principle of the 1916 Organic Act (16 U.S.C. § 1–4) that established the National Park Service (NPS) and other park units, such as Agate Fossil Beds NM (Figure 4.1.1).

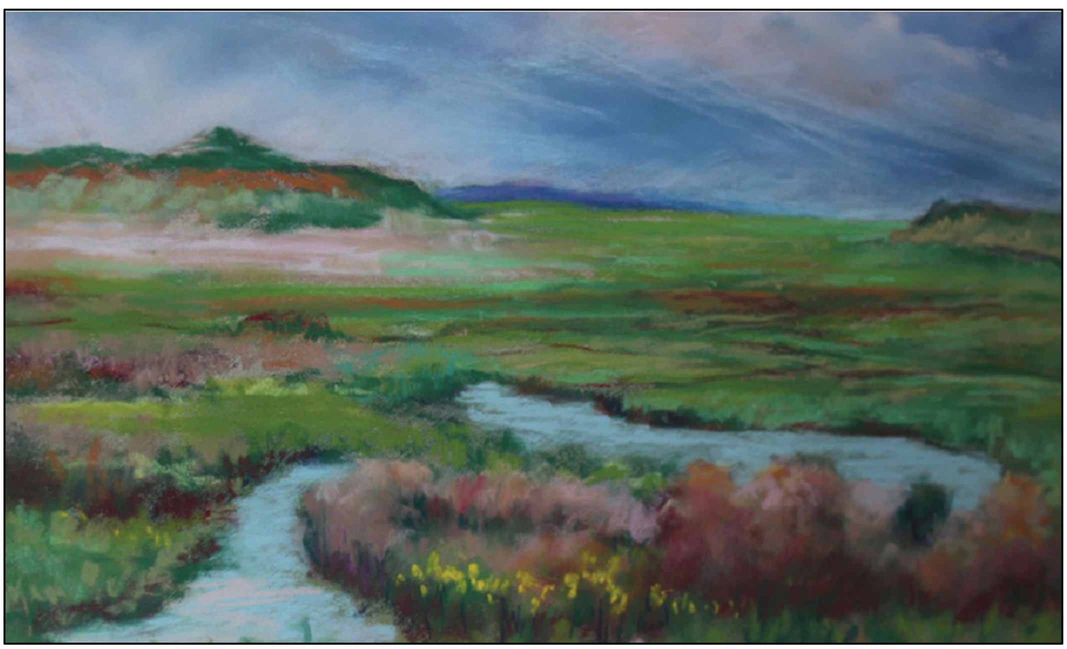


Figure 4.1.1. Painting of Agate Fossil Beds NM by Mary Louise Tejeda Brown. Mixed prairie grasslands at Agate Fossil Beds National Monument provide similar views to those that native tribes and settlers may have experienced in the 1800s. Some changes have occurred, however, such as the invasion of yellow flag iris (*Iris pseudacorus*) along the banks of the Niobrara River; the yellow flowers in the foreground of this painting, painted during an Artist in Residence program at Agate Fossil Beds NM, may be yellow flag iris. Image courtesy of Agate Fossil Beds NM.

The National Park Service prioritizes conserving scenery for the enjoyment of visitors and current and future generations (16 U.S.C. § 1–4). Scenic park resources are protected from impairment, which is any change that harms the integrity of the park unit (NPS 2006). NPS encourages park units to protect the iconic and spectacular scenery of the national parks by preserving visual resources (NPS 2015a). Protecting park viewsheds, the geographic area visible from a given location, is key to this goal. The viewshed within a park unit is the visible area from all locations within the park (Figure 4.1.2). While park units can manage visual resources within their boundaries, protecting the viewshed beyond those boundaries can be more challenging. If planned development in surrounding communities threatens the integrity of viewshed within a park unit, NPS can work to preserve viewsheds by participating in local planning processes. Although no management policy currently exists exclusively for scenic resources, the NPS has shown a century-long commitment to the inventory, assessment, and preservation of the park system's visual resources.

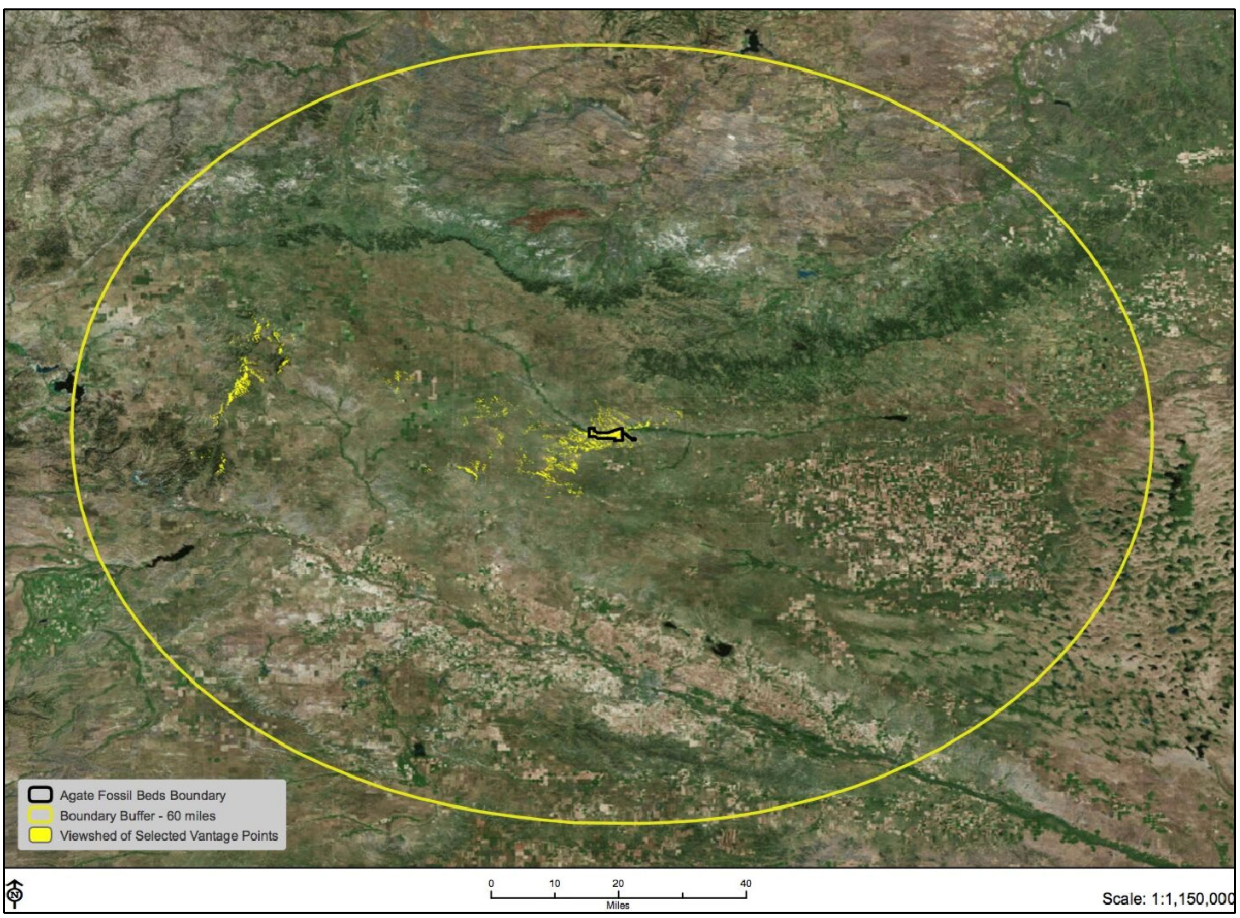


Figure 4.1.2. Viewshed of all areas visible from one or more vantage points at Agate Fossil Beds NM used in the digital viewshed assessment. Map created by WyGISC (2016) from Landsat Imagery.

Regional Context

At Agate Fossil Beds NM, exposed fossils, cultural landscapes, the Niobrara River, and views of western Nebraska are an important part of the visitor experience. The landscapes in and around the park offer visitors an opportunity to enjoy a visual setting dominated by a largely intact and unaltered mixed grass prairie. This view is not unlike the one that the Cook family would have experienced when they settled next to the Niborara River in 1887, on land that is now part of Agate Fossil Beds NM. Tribes and early settlers would have likely seen mixed grassland prairie, once the dominant land cover in the region (Ricketts et al. 1999), stretching for miles in all directions.

Despite the preserved prairie within Agate Fossil Beds NM, the landscapes of the region around the National Monument are now very different than they were in the late 1880s. Much of the prairie has since been converted to agriculture or developed for residential and industrial use. Many of the natural processes that helped shape the landscape, such as grazing by bison, are now gone (Ricketts et al. 1999). These changes in the surrounding landscape highlight the importance of the views that remain intact within Agate Fossil Beds NM.

4.1.2. Viewshed Standards

National standards for visual resources within NPS units do not currently exist. The diverse nature of the lands within the park system and the attractions they provide require that each park is considered individually for visual resource goals.

4.1.3. Methods

We assessed viewshed condition within Agate Fossil Beds NM using a combination of quantitative GIS analyses and an approach used for assessing visual resource indicators developed by the National Park Service Air Resources Division (NPS-ARD) for Visual Resource Inventories (VRI) (M. Meyers, personal communication, 3 March 2016).

To select key representative views—vantage points—for viewshed analyses, we adapted criteria from intensive viewshed studies of other NPS units (The Walker Collaborative et al. 2008). We tailored vantage point selection to match the interpretive focus of the park. Vantage points included locations defined by one or more of the following characteristics: high elevation overlook, popular visitor attraction, iconic park resource (either natural or historic), park entrance, and/or major infrastructure developments such as visitor or interpretive centers. To pinpoint the specific locations of potential vantage points, we used enabling legislation, interpretive materials for Agate Fossil Beds NM (NPS 2016), planning documents (NPS 2011), topographic maps, and geotagged photographs on Google Earth.

From these candidate vantage points, we then identified the points that were most likely to be of high importance to the park (Figure 4.1.3, Appendix A). We used all of these vantage points for the digital viewshed analysis (see below). To complete the VRI analyses in a timely manner, we further limited the vantage point selection for that process to three points representative of the most-visited areas in Agate Fossil Beds NM (vantage points 1 [Daemonelix Trail], 3 [Visitor Center], and 7 [Fossil Hills]; Appendix A). We adapted the VRI process developed by NPS-ARD (Sullivan and Meyer 2015) to use in this NRCA.

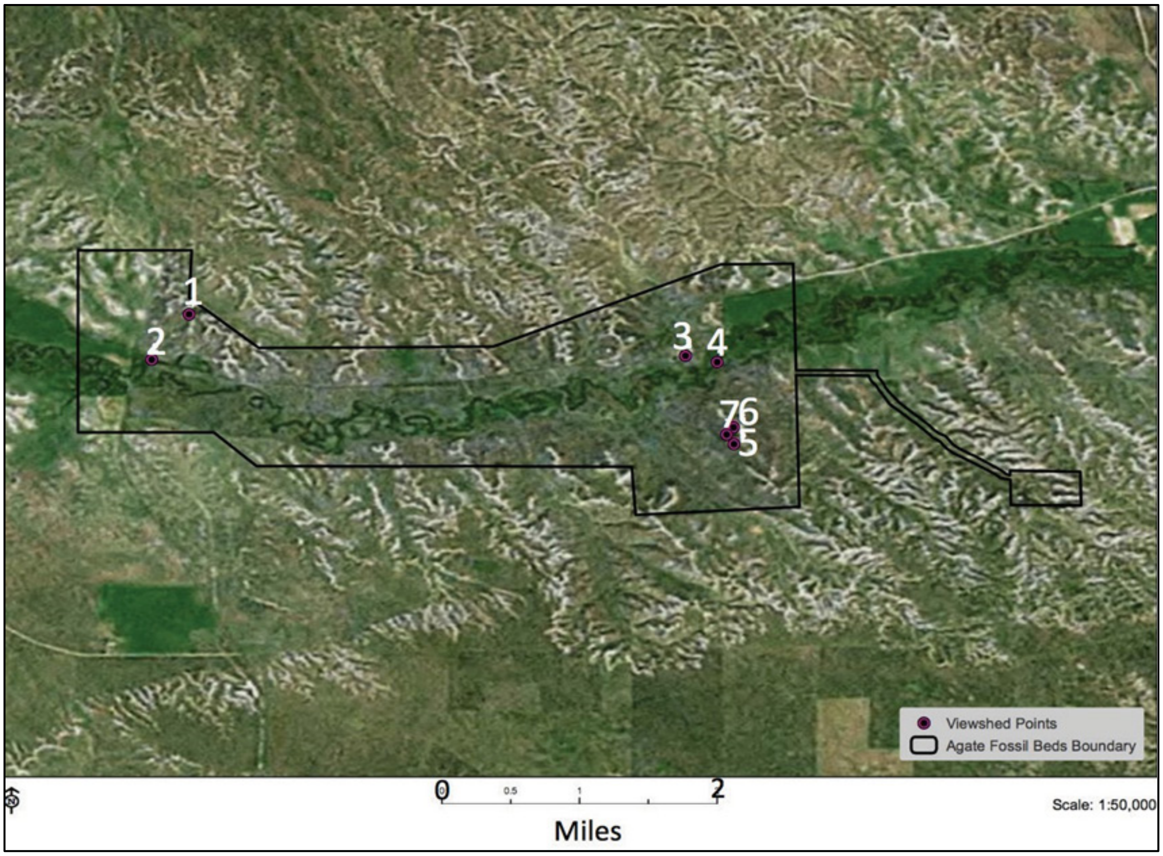


Figure 4.1.3. Vantage points used in the digital viewshed analysis for Agate Fossil Beds NM. For the Visual Resource Inventory, only vantage points 1 (Daemonelix Trail), 3 (Visitor Center), and 7 (Fossil Hills) were used. Map created by WyGISC (2016) from Landsat imagery.

This adaptation was necessary because full viewshed assessments have not yet been completed for Agate Fossil Beds NM. The VRI process is a systematic description of the scenic quality and the importance to NPS visitor experience and interpretive goals for important views inside and outside NPS units.

An important difference between our approach and a full VRI assessment is that we used the importance criteria to select vantage points that we included in the assessment, instead of incorporating view importance into the overall viewshed condition. This approach allowed us to focus on the condition of particularly iconic vantage points, well-visited points, and points that are currently developed or are being developed to draw visitor attention. In future viewshed condition assessments, the importance criteria may be applied to all points at the park to identify management priorities and development potential. While the full NPS-ARD VRI evaluation also includes an evaluation of historical importance and threats or opportunities that may negatively or positively affect scenic values of a park unit, we limited our assessment to the present condition of important views. We applied the scenic quality evaluation to important points only to avoid biasing viewshed condition by evaluating importance of unimportant viewpoints. We quantified view importance by following the VRI rating process, combining scores for viewpoint importance, viewed landscape importance, and the level of viewer concern. The importance values capture the unseen, non-scenic qualities of a vantage point such as cultural and historic context, and NPS and visitor values (Sullivan and Meyer 2015). We used descriptive information of the view importance elements from academic literature, local knowledge, and park interpretive materials to assign an importance rating to each potential vantage point. We then selected points with importance ratings of 4 (high) or 5 (very high) to use for the viewshed resource condition assessment.

Indicators and Measures

We assessed viewshed condition using two indicators: scenic quality of view and land cover content within viewshed. To assign a condition to each indicator, we conducted both qualitative and quantitative analyses of viewshed from each vantage point. We then considered the indicator conditions together to assess overall viewshed condition.

Indicator: Scenic Quality

Scenic quality is, in short, the visual attractiveness of a landscape. Spectacular scenery draws visitors who appreciate attractive landscapes, so conserving scenic values is important for promoting park visitation. Several primary factors affect landscape attractiveness: landscape character relates to how well the view matches the idealized expectation of the visitor, such as the inclusion of iconic park resources or the exclusion of elements that are inconsistent with the ideal view. Aesthetic composition of visual elements describes the extent to which the viewed landscape corresponds with pleasing artistic principles such as vivid focal points or harmonious relationships between the scales and colors within the view. When possible, we compared the results of our scenic quality analyses to rating data from full VRI evaluations.

Measure of Scenic Quality: Landscape Character Integrity

Landscape character integrity is the extent to which a view resembles the idealized version of the viewed landscape. This measure is subjective and individual visitors may have different interpretations of what landscape characteristics constitute ideal landscapes. If many people participate in viewshed assessments, however, an average score is likely to reflect overall visitor perception of any given view. Landscape character integrity accounts for three view components: the presence of important landscape elements, the quality and condition of the elements within the view, and the presence of inconsistencies in an otherwise natural landscape (e.g., power lines, cell towers, roads). A high landscape character integrity value would include a view containing iconic or important elements in good condition, with few elements inconsistent with the ideal character of the landscape (Sullivan and Meyer 2015).

To assign a score to landscape character, we used digital imagery in lieu of on-site surveys. We used the NPS Scenery Conservation Program (NPS 2015b) methods for this assessment (Figure 4.1.4) and assigned an overall rating based on equally weighted scores of the three landscape character components.

LANDSCAPE CHARACTER INTEGRITY				
Landscape Character Elements	Few important character elements are plainly visible and/or many important elements are missing. (1)	Some important landscape character elements are present, but some important elements are missing. (3)	Most or all important elements of the designated landscape character are plainly visible (e.g., natural features, land use types, structures, etc.). (5)	RATING
Rationale:				
Quality and Condition of Elements	Most elements are of poor quality and/or in poor condition. Many or most natural appearing elements are poor examples of the idealized features. Built elements that are not recognized for their historic or cultural value appear to be of poor quality, or are not well cared for. (1)	Most elements are of fair quality and/or in fair condition. Some natural appearing elements such as vegetation may not all appear to be healthy or vigorous; lakes and rivers may appear polluted, or littered with debris. Some built elements that are not recognized for their historic or cultural value may be of lower quality, are of unfinished construction, or not well cared for. (3)	Most elements are of high quality and in good condition, such as a robust, healthy-looking forest, or a lake with clean water and a well-kept shoreline free of debris. Built elements use appropriate materials, designs, and finishes, and appear to be well cared for. (5)	RATING
	Do not downgrade quality and condition rating because of the condition of historic structures.			
Rationale:				
Inconsistent Elements	Many or major inconsistent elements are plainly visible and may be dominant features in the view. (1)	Some inconsistent landscape character elements are plainly visible. (3)	Only a few, minor inconsistent landscape character elements such as agricultural fields in an urban landscape or industrial facilities in a natural landscape are plainly visible. (5)	RATING
Rationale:				
			LANDSCAPE CHARACTER INTEGRITY TOTAL RATING	

Figure 4.1.4. Methods to assign a score to landscape character integrity (NPS 2015).

We assigned ratings to the three components on a 1–5 scale, for a total possible landscape character integrity score of 15 (Table 4.1.1). Our condition ratings correspond to the contribution each component has to overall scenic quality ratings of A-E, which are used to identify the conservation value of a view when applied to the Scenic Inventory Value Matrix (NPS 2015b). Our condition ratings correspond to the contribution each component has to overall scenic quality ratings of A-E. Landscape character integrity rating values of 1–5 (E) put this measure in the category, *Warrants Significant Concern*. Values of 6–10 (C/D) put this measure in the category, *Warrants Moderate Concern*. A value higher than 10 (A/B) put this measure in the category, *Resource in Good Condition*.

Table 4.1.1. Viewshed condition categories for the landscape character integrity of the view.

Resource condition		Character integrity rating
Condition Icon Definition	**Condition Icon**	
Warrants significant concern	Red circle	1 – 5
Warrants moderate concern	Yellow circle	6 – 10
Resource in good condition	Green circle	> 10

Measure of Scenic Quality: Vividness

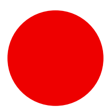
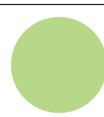
Vividness is the memorable distinctiveness of the landscape within a viewshed. Distinctive or visually striking landscapes contain dominant visual features that are easily identifiable and distinguished from other visual resources. El Capitan in Yosemite NP, the Grand Teton in Grand Teton NP, or Old Faithful in Yellowstone NP are park resources that exemplify this measure and are easily identified due to high levels of vividness.

Three components (focal points, forms/lines, and colors) constitute the vividness of a viewshed (NPS 2015b). High scores for vividness would likely include multiple focal points, vibrant colors, striking features, and rich textures (Sullivan and Meyer 2015). To assign a score to landscape character, we used digital imagery in lieu of on-site surveys. We used the NPS Scenery Conservation Program (NPS 2015b) methods for this assessment (Figure 4.1.5) and assigned an overall rating based on equally weighted scores of the three vividness components. We assigned ratings to the three components on a 1–5 scale, for a total possible vividness score of 15 (Table 4.1.2). The condition categories were based on Scenic Inventory Matrix ratings (NPS 2015b). Vividness values of 1–5 put this measure in the category, *Warrants Significant Concern*. Values of 6–10 put this measure in the category, *Warrants Moderate Concern*, and a value higher than 10 put this measure in the category, *Resource in Good Condition*.

VIVIDNESS				
Focal Points	The view has weak focal points or does not have any features that attract and hold visual attention. (1)	The view has a moderately strong focal point, or has multiple focal points and attention is focused on each one roughly equally. (3)	The view has one very strong focal point that attracts and holds visual attention. (5)	RATING
Rationale:				
Forms/Lines	The view has landforms, lines, and built structures of little interest and variety. Water is absent or a minimal element in the view. The forms and lines of built structures add little interest to the view. (1)	The view has one or more moderately bold landforms or water elements or well-defined straight or curved lines. Built structures have forms or lines that add moderate interest to the view. (3)	The view has one or more very bold landforms and/or water elements or well defined lines that provide strong visual interest. Built structures feature distinctive forms and lines that create visual interest. (5)	RATING
Rationale:				
Colors	The view contains colors that are generally muted and there are minimal textures or moving elements. (1)	The view contains moderately bold colors, and/or contains textures or moving elements that are visually prominent. (3)	The view contains very bold or striking colors and/or bold textures or moving elements that provide positive visual contrasts. (5)	RATING
	Texture and movement are secondary considerations for this component.			
Rationale:				
Are seasonal/ephemeral effects (e.g., wildflower displays, snow, dramatic clouds) important to the vividness rating? If yes, please describe:				☐Yes ☐No
			VIVIDNESS TOTAL RATING	

Figure 4.1.5. Methods to assign a score to vividness (NPS 2015).

Table 4.1.2. Viewshed condition categories for the vividness of the view.

Resource condition		Vividness rating
Condition Icon Definition	**Condition Icon**	
Warrants significant concern		1 – 5
Warrants moderate concern		6 – 10
Resource in good condition		> 10

Measure of Scenic Quality: Visual Harmony

We used visual harmony to measure the relationship between visual elements in a viewed landscape. Visual harmony has three components: spatial relationship, scale, and color. Landscapes with high visual harmony score have elements that fit well together spatially and complement each other in scale and color leaving the viewer with a sense of completeness or unity, whereas low visual harmony scores indicate views that do not achieve a complex and appealing unity of subjects, or seem monotonous.

To assign a score to visual harmony, we used digital imagery in lieu of on-site surveys. We used the NPS Scenery Conservation Program (NPS 2015b) methods for this assessment (Figure 4.1.6) and assigned an overall rating based on equally weighted scores of the three visual harmony components.

VISUAL HARMONY				
Spatial Relationship	There is no evident spatial relationship between elements in the view and their arrangement seems random or chaotic or the view seems unbalanced. **(1)**	The elements of the view appear to mostly fit together but the patterns or spatial relationships among elements make elements stand out or not fit in, or the view seems somewhat unbalanced. **(3)**	The view seems balanced and elements fit well together. **(5)**	**RATING**
Rationale:				
Scale	One or more landscape elements appear substantially larger or smaller than desirable, such that the view seems unbalanced. **(1)**	The relative sizes of landscape elements have little or no effect on the quality of the view. **(3)**	The landscape elements seem to be in good size proportion to one another, helping to make the view seem balanced. **(5)**	**RATING**
Rationale:				
Color	One or more major color elements clash with the overall color combination in the view, or there are multiple uncoordinated color elements. **(1)**	The combination of landscape colors and color contrasts are weakly compatible or complimentary. **(3)**	The visual elements of the landscape display compatible colors or complimentary color contrasts. **(5)**	**RATING**
Rationale				
			VISUAL HARMONY TOTAL RATING	

Figure 4.1.6. Methods to assign a score to visual harmony (NPS 2015).

We assigned ratings to the three components of visual harmony on a 1–5 scale, for a total possible rating of 15 (Table 4.1.3). The condition categories are based on the Scenic Inventory Matrix ratings (Sullivan and Meyer 2015). Visual harmony values of 1–5 put this measure in the category, *Warrants Significant Concern*, values of 6–10 put this measure in the category, *Warrants Moderate Concern*, and values higher than 10 put this measure in the category, *Resource in Good Condition*.

Table 4.1.3. Viewshed condition categories for the visual harmony of the view.

Resource condition		Visual harmony rating
Condition Icon Definition	**Condition Icon**	
Warrants significant concern	Red circle	1 – 5
Warrants moderate concern	Yellow circle	6 – 10
Resource in good condition	Green circle	> 10

Indicator: Land Cover Content

Land cover is all physical material covering the surface of the earth, from trees and water to roads and buildings. The type of land cover within the range of vision largely defines the viewed landscape. Generally, the visual appeal of a landscape increases with increased degree of wilderness, amount and type of vegetation, bodies of water and horizon features (Arriaza et al. 2004).

We sought to use an objective quantitative metric to evaluate viewshed condition, such that managers could gain some sense of viewshed condition even when no on site survey data exist for a park unit. We worked with the Wyoming Geographic Information Science Center (WyGISC) to calculate land cover percentage estimates within the viewshed from all vantage points using the most recent National Land Cover Dataset (USGS 2011). We grouped all cover types into three classes—natural, developed, and agriculture—and calculated the percentage of each class in the foreground (0–0.5 miles from vantage point), middle ground (0.5–3 miles), and background (3–60 miles).

In our effort to identify a basic quantitative of measure of viewshed condition, we tested for correlations between land cover percentages and scenic quality values. We pooled data from 18 vantage points at Scotts Bluff NM, Agate Fossil Beds NM, Fort Laramie National Historic Site, and Badlands National Park for this analysis. Our efforts to include an objective, quantitative assessment of scenic quality to complement the measurements provided by the NPS-ARD resulted in significant correlations ($p < 0.01$) between land cover and scenic quality for all three cover classes (natural, developed, and agriculture) within the middle ground distance (Figure 4.1.7).]

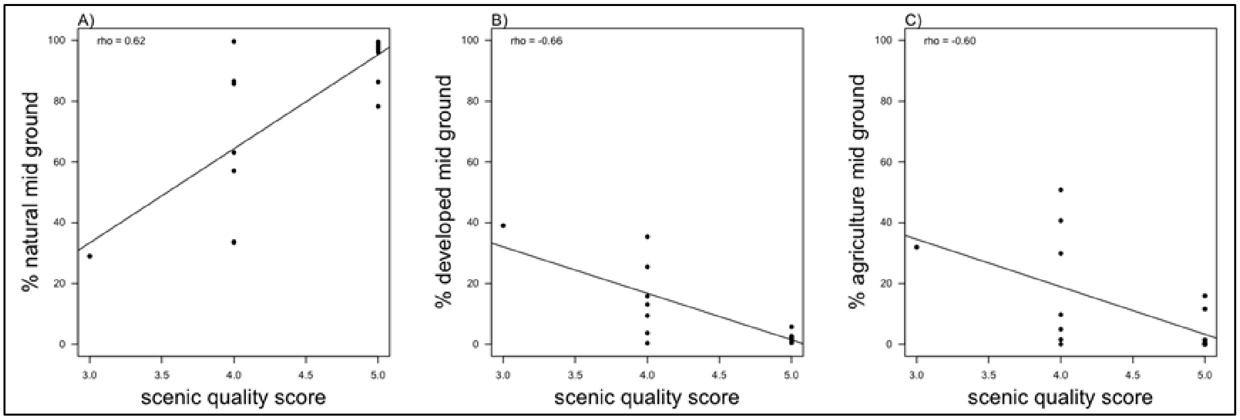


Figure 4.1.7. Relationships between scenic quality score and land cover. Rho is the correlation between scenic quality score and the percentage of each ground cover type.

Measure of Land Cover Content: Percentage of Natural Cover in Mid-Ground

Natural land cover correlated positively with scenic quality score in the middle ground distance (0.5–3.0 miles) from vantage points (rho = 0.62, $P < 0.01$; Figure 4.1.7A). We used a quartile approach to assign condition categories to land cover percentages, with higher natural land cover percentages corresponding to higher scenic value scores (Table 4.1.4). If the percentage of natural land cover in the middle ground was ≤ 50%, the condition was *Warrants Significant Concern*. If the percentage of natural land cover in the middle ground was > 50% and ≤ 75%, the condition was *Warrants Moderate Concern*. If the percentage of natural land cover in the middle ground was > 76% the condition was In *Good Condition.*

Table 4.1.4. Viewshed condition categories for the percentage of natural land cover in the mid-ground.

Resource condition		Percentage natural cover
Condition Icon Definition	**Condition Icon**	
Warrants significant concern		≤ 50
Warrants moderate concern		50 < and ≤ 75
Resource in good condition		76 – 100

Measure of Land Cover Content: Percentage of Developed Cover in Mid-Ground

Developed land cover was negatively correlated with scenic quality score in the middle ground (0.5–3.0 miles) distance from vantage points (rho = −0.66, $P < 0.01$). Only vantage points with < 10% developed land in the middle ground received the highest scenic quality score, and most high scenic quality scores had < 20% developed land in the middle ground (Figure 4.1.7B). We used a quartile approach to assign categories to land cover percentages, within the observed range of values for developed land percentages in the middle ground (Table 4.1.5). If developed land cover percentage of viewshed was > 20%, we assigned the condition *Warrants Significant Concern*. If the percentage of developed land cover in the middle ground was ≤ 20% and > 10%, the condition was *Warrants Moderate Concern*. If the percentage of developed land cover in the middle ground was ≤ 10% the condition was In *Good Condition.*

Table 4.1.5. Viewshed condition categories for the percentage of developed land cover in the mid-ground.

Resource condition		Percentage developed cover
Condition Icon Definition	**Condition Icon**	
Warrants significant concern		> 20
Warrants moderate concern		> 10 and ≤ 20
Resource in good condition		≤ 10

Measure of Land Cover Content: Percentage of Agricultural Cover in Mid-Ground

Agricultural land cover was negatively correlated with scenic quality score in the middle ground (0.5–3.0 miles) distance from vantage points (rho = −0.60, $P < 0.01$). Only vantage points with < 13% agricultural land in the middle ground received the highest scenic quality score (Figure 4.1.7C). We used a quartile approach to assign categories to land cover percentages, within the observed range of values for agricultural land percentages in the middle ground (Table 4.1.6). If agricultural land cover percentage of viewshed was > 25%, we assigned the condition *Warrants Significant Concern*. If the percentage of agricultural land cover in the middle ground was ≤ 25% and > 13%, the condition was *Warrants Moderate Concern*. If the percentage of developed land cover in the middle ground was ≤ 13% the condition was *Resource in Good Condition*.

Table 4.1.6. Viewshed condition categories for the percentage of agricultural land cover in the mid-ground.

Resource condition		Percentage agricultural cover
Condition Icon Definition	Condition Icon	
Warrants significant concern	Red circle	> 25
Warrants moderate concern	Yellow circle	> 13 and < 25
Resource in good condition	Green circle	< 13

Data Sources

To evaluate viewpoints for scenic quality, we used scenic photos available online from Agate Fossil Beds NM, photographs taken by visitors and linked to vantage locations in Google Earth, and, when available, digitally "stitched" panoramic photos from Google Earth street and ground views at the three vantage points most representative of views at Agate Fossils Beds NM. We used these available "photographic surrogates" (Shuttleworth 1890) to complete viewshed assessments in accordance with the NPS-ARD viewshed assessment guidance. When available, we received additional scenic quality data from a previous visual resource inventory conducted by NPS-ARD (NPS 2015c). Land cover data was based on the most recent National Land Cover Dataset (USGS 2011).

Digital viewshed analyses (Appendix B) were completed by the Wyoming Geographic Information Science Center (WyGISC) for each vantage point. Land cover data was based on the most recent National Land Cover Dataset (USGS 2011).

Quantifying Viewshed Condition, Confidence, and Trend

Indicator Condition

We created condition categories based on expert opinion and the scientific literature. We used a point system to assign each indicator to a category. This point system is based on the NPS methods that were developed to calculate overall air quality condition (NPS-ARD 2015), a methodical and rigorous assessment approach that can be applied to other resources as well. In this approach, we assigned zero points to the condition *Warrants Significant Concern*, 50 points to *Warrants Moderate Concern*, and 100 points to *Resource in Good Condition*. The average of all measures determined the condition category of the indicator; scores from 0–33 fell in the *Warrants Significant Concern* category, scores from 34–66 were in the *Warrants Moderate Concern* category, and scores from 67–100 indicated *Resource in Good Condition*.

Indicator Confidence

Confidence ratings were based on availability of data collected about the indicator. For Scenic Quality, we gave a rating of High confidence when data from full VRI assessments conducted within the park from selected views were available in conjunction with remote assessments using geo-tagged photographs and digitally stitched panoramas. We assigned a *Medium* confidence rating when data was remotely assessed using only geotagged photographs and digitally stitched panoramas and the viewed landscape was presented in 360° natural perspective imagery. *Low* confidence ratings were assigned when data was limited to only single perspective photography or "ground view" Google Earth images.

We gave a rating of *High* confidence when data for land cover were collected recently and methodically. We assigned a *Medium* confidence rating when data were methodically collected, but recent land cover data were not available. *Low* confidence ratings were assigned if data were either missing or unavailable within a recent time period.

Indicator Trend

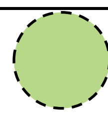
Potential trend categories were *Improving*, *Unchanging*, or *Deteriorating*. To calculate a trend estimate for indicators, we sought viewshed data that were collected at least twice over a five-year period and met the conditions for a High confidence rating. If there were no data available that met these monitoring requirements for a particular indicator, we indicated that trend was *Not Available* for that indicator.

Overall Viewshed Condition, Confidence, and Trend

We used the general approach for combining indicator conditions, trends, and confidence described in Chapter 3 (Methods 3.2.2) to calculate overall resource condition, trend, and confidence.

4.1.4. Viewshed Conditions, Confidence, and Trends

<u>Scenic Quality</u>



Condition: Resource in Good Condition
Confidence: Low
Trend: Not Available

Condition

The average scores for landscape character integrity, vividness, and visual harmony of the view were all > 10 (Table 4.1.7). The combined scores placed scenic quality for Agate Fossil Beds NM in the Resource in Good Condition category.

Table 4.1.7. Ratings for each measure and indicator at each vantage point, plus park average for indicator and measures at all vantage points.

Measure	Components	Vantage point ratings			
		Daemonelix Trail (vantage point 1)	Visitor center	Parade grounds (vantage point 6)	Park average
Landscape character integrity	Landscape character elements	4.0	4.5	5	4.5
	Quality and condition of elements	5.0	5.0	5	5.0
	Inconsistent elements	5.0	4.0	5	4.7
	Total	**14.0**	**13.5**	**15**	**14.2**
Vividness	Focal points	3.0	5.0	4	4.0
	Forms/lines	4.0	4.0	4	4.0
	Colors	3.5	4.0	5	4.2
	Total	**10.5**	**13.0**	**13**	**12.2**
Visual harmony	Spatial relationship	5.0	5.0	5	5.0
	Scale	5.0	5.0	5	5.0
	Color	5.0	5.0	5	5.0
	Total	**15.0**	**15.0**	**15**	**15**

Confidence

Scenic quality data were not available from full VRI assessments conducted within the park. We conducted remote assessments only single perspective photography and "ground view" images. The confidence rating was *Low*.

Trend

Scenic quality data were insufficient to assign a trend to the resource, so trend was *Not Available*.

Land Cover Content

Condition: Resource in Good Condition
Confidence: High
Trend: Not Available

Land cover content percentages for natural cover, developed cover and agricultural cover at mid-ground distances were 95.47%, 1.82%, and 2.70% respectively (Figure 4.1.8). Each of these measurements placed land cover content in the *Resource in Good Condition* category.

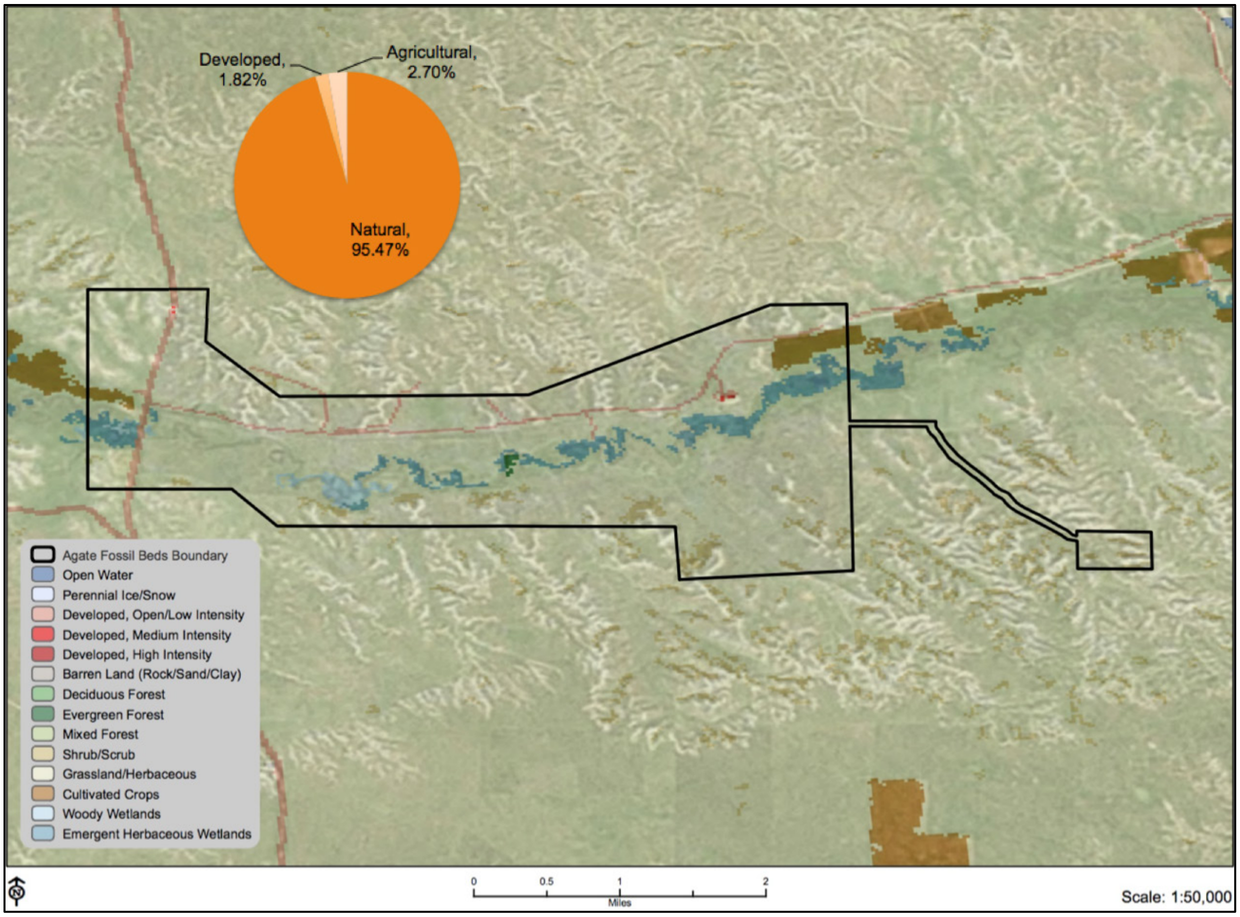


Figure 4.1.8. Mid-Ground landcover content. Natural cover includes barren land, deciduous forest, evergreen forest, mixed forest, shrub/scrub, grassland/herbaceous, woody wetlands, and emergent herbaceous wetlands. Agricultural cover includes cultivated crops. Developed land includes Developed with Open/Low Intensity, Medium Intensity, and High Intensity. Map created by WyGISC (2016) from Landsat Imagery.

Confidence

Land cover content calculations were calculated using the most recent available data from the National Land Cover Database (NLCD) (USGS 2011), so the confidence was *High*.

Trend

Land cover data were insufficient to assign a trend to the resource, so trend was *Not Available*.

Viewshed Overall Condition

The overall viewshed condition (Table 4.1.8) was determined by the average of the indicator conditions. We summarized the condition, confidence, and trend for each indicator, and assigned condition points as specified by NPS–ARD (Table 4.1.9). Scenic quality at Agate Fossil Beds NM was placed in the *Resource in Good Condition* category and scored 100 points. Land cover content was placed in the *Resource in Good Condition* category and scored 100 points. The total score for overall viewshed condition was 100 points, which placed Agate Fossil Beds NM in the *Resource in Good Condition* category.

Table 4.1.8. Viewshed overall condition.

Indicators	Measures	Condition
Scenic quality	• Landscape character integrity • Vividness • Visual harmony	
Land cover content	• Mid-ground % natural cover • Mid-ground % developed cover • Mid-ground % agricultural cover	
Overall condition for all indicators and measures		

Table 4.1.9. Summary of viewshed indicators and measures.

Indicator	Measure	Condition	Confidence	Trend	Condition rationale
Scenic quality	Landscape character integrity	Resource in good condition	Low	Not available	The average landscape character integrity score from five different viewpoints in Agate Fossil Beds NM was 14.2; this placed landscape character integrity in the *Resource in Good Condition* category. Only single perspective photography and "ground view" images were available for assessments, so confidence was *Low*. Trend was *Not Available*.
	Vividness	Resource in good condition	Low	Not available	The average vividness score from five different viewpoints in Agate Fossil Beds NM was 12.2; this placed landscape character integrity in the *Resource in Good Condition* category. Only single perspective photography and "ground view" images were available for assessments, so confidence was *Low*. Trend was *Not Available*.

Table 4.1.9 (continued). Summary of viewshed indicators and measures.

Indicator	Measure	Condition	Confidence	Trend	Condition rationale
Scenic quality (continued)	Visual harmony	Resource in good condition	Low	Not available	The visual harmony score from five different viewpoints in Agate Fossil Beds NM was 15; this placed landscape character integrity in the *Resource in Good Condition* category. Only single perspective photography and "ground view" images were available for assessments, so confidence was *Low*. Trend was *Not Available*.
Land cover content	Mid-ground percent natural cover	Resource in good condition	High	Not available	Average 2011 mid-ground natural land cover visible from the five different Agate Fossil Beds NM viewpoints comprised 95.47% of the viewed landscape; this placed mid-ground natural land cover in the *Resource in Good Condition* category. The GIS analysis of land cover used the most recent NLCD data so confidence was *High*. Trend was *Not Available*.
	Mid-ground percent developed cover	Resource in good condition	High	Not available	Average 2011 mid-ground developed land cover visible from the five different Agate Fossil Beds NM viewpoints comprised 1.82% of the viewed landscape; this placed mid-ground developed land cover in the *Resource in Good Condition* category. The GIS analysis of land cover used the most recent NLCD data so confidence was *High*. Trend was *Not Available.*
	Mid-ground percent agricultural cover	Resource in good condition	High	Not available	Average 2011 mid-ground agricultural land cover visible from the five different Agate Fossil Beds NM viewpoints comprised 2.70% of the viewed landscape; this placed mid-ground agricultural land cover in the *Resource in Good Condition* category. The GIS analysis of land cover used the most recent NLCD data so confidence was *High*. Trend was *Not Available*.

Confidence

Confidence was *Low* for Scenic Quality and *High* for Land Cover Content, so the score for overall confidence was 50, which met the requirements for *Medium* confidence in overall viewshed condition.

Trend

Trend data were not available for any indicators, so overall trend for viewshed condition was *Not Available.*

4.1.5. Stressors

Viewshed Vulnerability

A viewshed is composed of the geographic area visible from a particular point or area at a particular time. Visible environments are subject to dynamic processes, such as development of land or natural events such as fire that can change the characteristics of a given viewshed. Assessing the vulnerability of a particular viewshed to change can help to identify potential stressors and their effects to the overall resource condition. Three aspects contribute to the potential effects of stressors on the viewshed condition; likelihood of visual change, magnitude of visual change and mitigation constraints (Meyer 2016).

We collected data to identify stressors related to viewshed vulnerability from the Sioux County GIS database (Sioux County Nebraska 2016). Agate Fossil Beds NM is located within a remote, rural area with a largely natural environment. The county assessor provided the best information to estimate viewshed vulnerability.

Based on the unpublished developmental guidance of the NPS-ARD (Meyer 2016), we evaluated the level of viewshed vulnerability at Agate Fossil Beds NM, using likelihood of visual change, magnitude of visual change and mitigation constraints as basis for our assessment of stressors to this resource. The protections in place at Agate Fossil Beds NM and the land use of the surrounding area indicate that all vulnerability factor ratings are low. The rural, undeveloped character of the viewshed is not currently vulnerable to changing conditions.

4.1.6. Data Gaps

The views of and from Agate Fossil Beds NM are closely related to the primary purpose of the park unit. The lack of available viewshed data limits the ability to identify trends and maintain accurate resource condition data for viewshed within the park. A collection of high quality panoramic photographs with 360° natural perspective imagery for selected viewpoints is available, but an expanded and continued collection would provide accurate and efficient monitoring of viewsheds within the park. Continued assessments of important park views will be important to understand potential stressors could impact visual resources of Agate Fossil Beds NM. In such assessments, NPS has opportunities to engage visitors in the monitoring process through the use of interactive viewshed signs. For example, visitors are likely to take photographs at important vantage points; signs that 1) show specific reference points to align in photographs of the landscape, and 2) present links via social media to upload those images may garner all the imagery required for rigorous viewshed assessments and long term monitoring.

Our attempt to add a quantitative indicator of assessment to the qualitative approach presented by the NPS-ARD brings an objective measurement to the assessment of visual park resource. Continued monitoring of vantage points and the corresponding views in the park offers the opportunity to increase the effectiveness of this effort to protect viewsheds in park units. Additionally, knowing the average number of visitors at each viewpoint would allow managers and analysts to assign importance level with more confidence. Long term monitoring that tracks disturbances within viewsheds would facilitate any assessment of trend. Further quantitative assessments could include analyses of how spatial distributions of landcover types and developments affect park goals for viewsheds.

Acknowledgments

- Mark Meyer (NPS)

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Google Earth. 2013c. Agate Fossil Beds National Monument: Fossil Hills. 42°25’03”N, 103°43’39”W. Eye altitude: Ground level view.

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4.2. Night Sky

4.2.1. Background and Importance

Spectacular starry skies and dark nights are highlights of national parks for anyone who camps out or visits after dusk. The patterns among constellations are essentially the same ones that have been visible to humans for thousands of years (NPS 2012a), though the moon phase and position of celestial objects constantly change. The night sky is the "Ultimate Cultural Resource" (Rogers and Sovick 2001, NPS 2012a), because of the impressions it has made on humanity through time. More than a visual resource, dark skies play an important role in healthy ecosystems (Rich and Longcore 2006). The absence of light is important to nocturnal wildlife, light-sensitive amphibians, reptiles, insects, plants (NPS 2012b), and migrating birds requiring starry skies for navigation.

The NPS is dedicated to the protection and preservation of the natural nightscapes (also referred to as lightscapes), those areas existing in the absence of human-caused light at night, within the parks (NPS 2012d). The parks managed by the NPS are some of the last remaining dark sky areas in the United States, providing a unique but endangered opportunity to visitors (NPS 2012c) so experience dark nights and star-gazing activities. Fewer than one-third of the population in the United States has the ability to view the Milky Way with the naked eye from their homes (Cinzano et al. 2001, Falchi et al. 2016), due to light pollution, which highlights the importance of dark sky preservation within the parks. Clear, dark skies are increasingly rare; 99% of the United States population lives in areas where light pollution is above threshold levels (Cinzano et al. 2001, Falchi et al 2016) for viewing many astronomical objects. Stargazing in parks is a popular activity (NPS 2012d). Managing nightscapes for dark skies and minimal light pollution not only provides enhanced visitor enjoyment of the parks, but also preserves an important cultural, natural, and scientific resource (NPS 2012e).

Natural nocturnal nightscapes are crucial to the integrity of park settings. Dark skies and natural nightscapes are necessary for both human and natural resource values in the parks. Limiting light pollution, caused by the introduction of artificial light into the environment, helps to ensure that this timeless resource will continue to be shared by future generations.

Regional Context

Increases in light pollution in North America (Bennie et al. 2015) over the past century have placed the US as the country with the sixth greatest amount of light pollution, as of 2016 (Falchi et al. 2016). For now, however, some of the darkest skies in the lower 48 states surround Agate Fossil Beds NM (Figure 4.2.1).

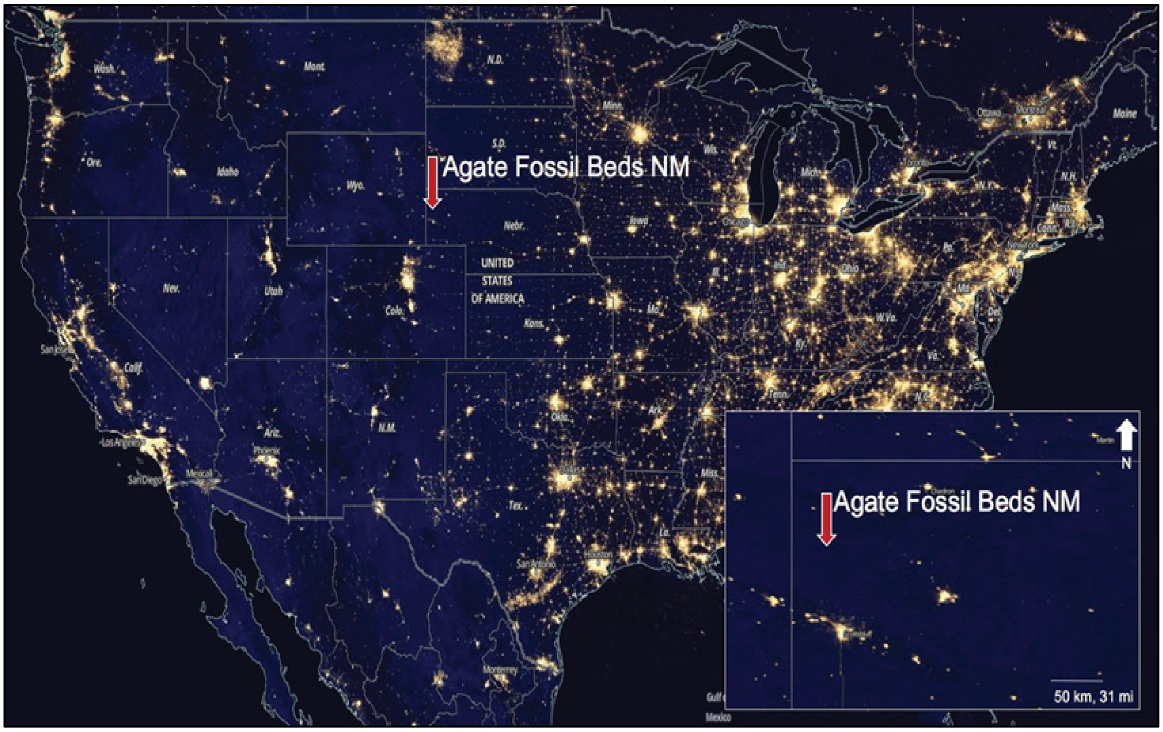


Figure 4.2.1. Satellite image of Agate Fossil Beds NM and the lower 48 states at night in 2012. Map generated at https://worldview.earthdata.nasa.gov using Earth at Night 2012 base layer from NASA Earth Observatory.

Clear, dark night skies are a valuable natural resource at Agate Fossil Beds NM. Park staff and residents are conscious of the valuable night sky resource and make an effort to keep Agate Fossil Beds NM as dark as possible at night (A. Wilson, personal communication, 18 August 2016). Some light pollution to the south, in Scottsbluff/Gering, can impinge on star gazing quality from the tops of hills or bluff; the best locations for stargazing are consequently in the valley where topographic features block most of the light (Figure 4.2.2). Stargazing programs are usually conducted in the fall, when the sun begins to set earlier (A. Wilson, personal communication, 18 August 2016). Rangers at Agate Fossil Beds NM lead these interpretive programs, guiding participants to identify sky objects and operate telescopes.

Figure 4.2.2. Night sky from Agate Fossil Beds NM. Light pollution from Scottsbluff/Gering and other surrounding communities is visible as glow at the bottom of the photograph, but many sky objects are visible anyhow (Photo by Dwight Stuessy, taken June 6, 2016).

4.2.2. Night Sky Standards

National standards for night sky resources within NPS units do not currently exist. The rapid global decline of natural nocturnal nightscapes and the resulting environmental degradation has led the NPS to identify night sky quality as a "vital sign" of park resource health (Manning et al. 2015). The National Park Service is in a leadership position to pioneer protecting natural darkness as a valuable park resource (NPS 2014). Ongoing research and the development of models to enhance night sky protections are leading towards the development of standards and thresholds for acceptable conditions (NPS 2012e, Manning et al. 2015, International Dark-Sky Association 2016a).

4.2.3. Methods

<u>Indicators and Measures</u>

Overall night sky condition depends on the individual conditions of multiple indicators. The NPS Natural Sounds and Night Skies Division (NSNSD) efforts to protect naturally dark environments has led to a concerted effort in the collection of reliable data about existing nightscapes in many NPS units (NPS 2012c). Primary goals of the NSNSD night skies program are to protect against night sky degradation for both visitor enjoyment and healthy ecological processes.

The NSNSD identifies two main distinctions within the management considerations of the nighttime environment. Nightscapes are the human perception of both the night sky and visible terrain, and the photic environment consists of all wavelengths and patterns of light in an area (Moore et al. 2013). The overall quality of the night sky as a park resource is directly related to both the perceived aesthetic quality of the night sky to park visitors, and the effect of the photic environment on species within the park and natural physical processes (Moore et al. 2013).

Indicator: Night Sky Quality

The aesthetic qualities of the night sky within many units of the NPS are, in many cases, the best examples of dark skies in the United States. As light pollution increases nationally, these dark sky areas become more valuable to the visitor experience. The night sky quality within a park can be understood as the ability to view the night sky free from the intrusion of light pollution. It is estimated that two-thirds of the United States population cannot see the Milky Way on a given night (Cinzano et al. 2001); the NPS strives to provide an excellent night sky experience by preserving the night sky quality within the various park units. The NSNSD created a dataset of attributes and indicators for night sky quality. We used methods and data provided by the NSNSD to assess the night sky quality at Agate Fossil Beds NM.

Measure of Night Sky Quality: Bortle Dark-Sky Scale

The Bortle Dark-Sky Scale, developed by John Bortle in 2001, is intended to give astronomers a standardized method of determining the darkness of the night sky. The darkness of sky is rated on a nine-level qualitative scale intended to eliminate observer subjectivity and account for the relative absence of truly dark skies (Bortle 2001; Table 4.2.1, Figure 4.2.3). The Bortle scale was developed from over 50 years of night sky observations, and has become the accepted descriptor of night sky quality for amateurs and professionals alike (International Dark-Sky Association 2016b).

Table 4.2.1. The Bortle Dark-Sky scale (Bortle 2001).

Bortle Scale	Milky Way	Astronomical objects	Zodiacal light/ constellations	Airglow and clouds	Night time scene
Class 1 Excellent, dark-sky site	MW shows great detail and light; Scorpio/ Sagittarius region casts shadows on the ground	M33 (the Pinwheel Galaxy) is obvious to the naked eye	Visible zodiacal light and can stretch across the entire sky	Bluish airglow is visible near the horizon and clouds appear as dark voids	Light from Jupiter and Venus degrade night vision. Ground objects are invisible
Class 2 Typical, truly dark site	MW highly structured to the unaided eye	M33 is visible with direct vision, as are many globular clusters.	Zodiacal light bright enough to cast weak shadows after dusk and has an apparent color	Airglow may be weakly apparent and clouds still appear as dark voids	Ground is mostly dark, but objects projecting into the sky are discernible
Class 3 Rural sky	MW still appears complex	Brightest Globular Clusters are distinct, M33 visible with averted vision	Zodical light is striking in Spring and Autumn, color is weakly indicated	Airglow is not visible and clouds are faintly illuminated, except at the zenith	Some light pollution evident along the horizon. Ground objects are vaguely apparent

Table 4.2.1 (continued). The Bortle Dark-Sky scale (Bortle 2001).

Bortle Scale	Milky Way	Astronomical objects	Zodiacal light/ constellations	Airglow and clouds	Night time scene
Class 4 Rural/sub-urban transition	MW visible well above horizon, lacks all but most obvious structure	M33 is a difficult object, even with averted vision	Zodiacal light is clearly evident, but extends less than 45 degrees after dusk	Clouds are faintly illuminated except at the zenith	Light pollution is obvious in several directions. Ground objects are visible
Class 5 Suburban sky	MW is washed out overhead, weak or invisible at horizon	The oval of M31 is detectable, as is the glow in the Orion Nebula	Only hints of zodiacal light in Spring and Autumn	Clouds are noticeably brighter than the sky	Light pollution is evident in most directions. Ground objects are partly lit
Class 6 Bright, suburban sky	Indication of MW at zenith	M33 impossible to see without binoculars	No trace of zodiacal light	Clouds anywhere in the sky appear fairly bright	Sky from horizon to 35 degrees glows with grayish color. Ground is well lit
Class 7 Suburban/ urban transition	MW is totally invisible or nearly so	M31 and the Beehive Cluster are indistinct	The brighter constellations are recognizable	Clouds are brilliantly lit	Entire sky background has vague, grayish white hue
Class 8 City sky	Not visible at all	M31 and M44 may be barely glimpsed on good nights	Constellations lack key stars	Clouds are brilliantly lit	Sky glows whitish gray or orangish, newspaper headlines are readable
Class 9 Inner-city sky	Not visible at all	Pleiades discernable to experienced viewer	Only the brightest stars in constellations visible	Clouds are brilliantly lit	Entire sky is brightly lit

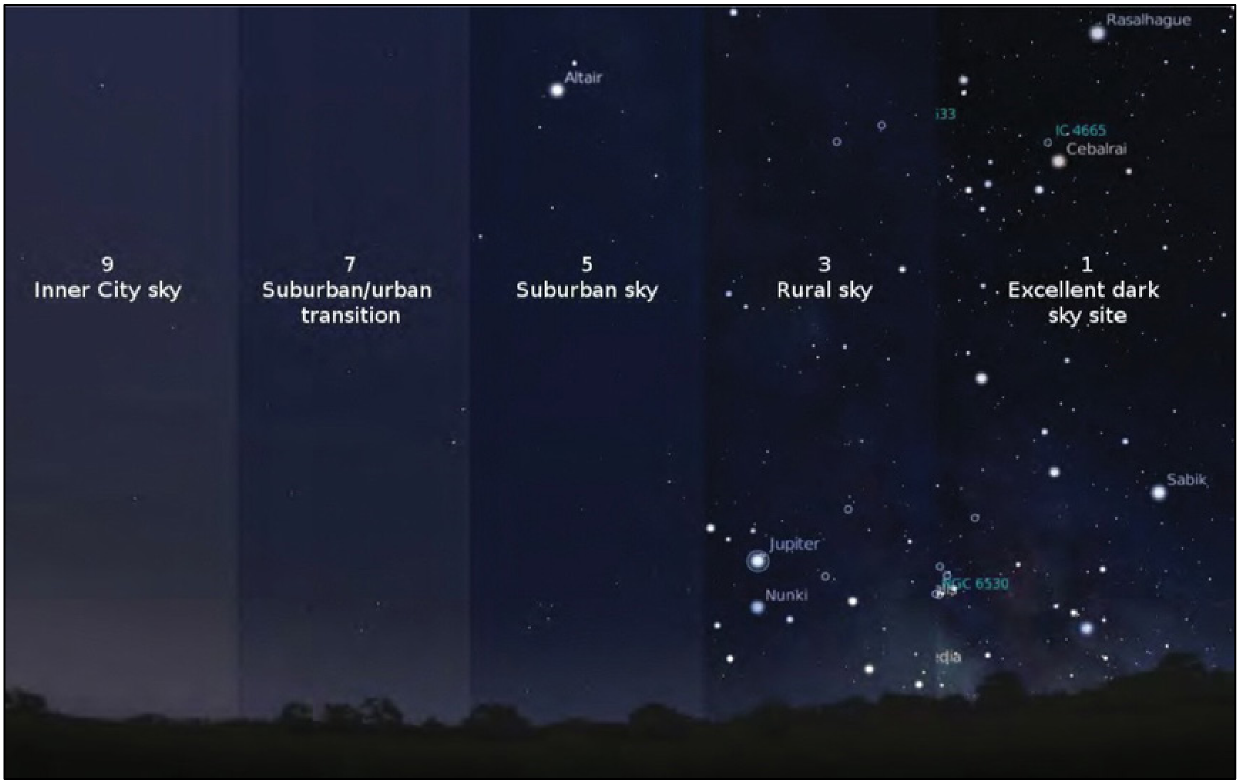
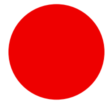
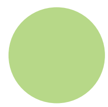


Figure 4.2.3. Bortle Dark Sky composite image. Image from Struthers et al. (2014), generated from Stellarium (stellarium.org).

The 1–9 class ratings of the Bortle scale correspond to the quality of available night sky viewing opportunities with a class rating of 1 indicating an excellent dark sky and 9 being a severely degraded night sky. The NPS NSNSD uses a categorical designation of quality that defines Bortle scale classes of 1–3 as within the range of natural skies, we use this designation to correspond to the *Resource in Good Condition* category; classes of 4–6 are considered significantly degraded skies and we assigned these to the *Warrants Moderate Concern* category; and Bortle classes 7–9 are considered severely degraded by the NSNSD, so we assigned these classes to the *Warrants Significant Concern* category (Table 4.2.2).

Table 4.2.2. Night sky condition categories for the Bortle Dark-Sky scale.

Resource condition		
Condition Icon Definition	**Condition Icon**	**Bortle class**
Warrants significant concern		7 – 9
Warrants moderate concern		4 – 6
Resource in good condition		1 – 6

Measure of Night Sky Quality: Synthetic Sky Quality Meter (SQM)

The Synthetic Sky Quality Meter (SQM) measurement provides a quantitative assessment of all-sky light measurement. The synthetic SQM uses an algorithm to mimic the measurements of a common sky darkness measurement tool, the Unihedron Sky Quality Meter (NPS 2015). The NPS uses synthetic SQM over actual Unihedron SQM data because synthetic SQM is generally thought to be more accurate in measurement alignment to zenith, and accurately calibrated light sensing camera data (NPS 2015). Synthetic SQM measures the brightness of sky 30 degrees above the horizon and higher, discounting bright sources of artificial light along the horizon. The reported units are reported in magnitudes per square arc-second, a standard astronomical measurement that defines the brightness of an object spread over an area of the sky.

We assigned categorical ratings using guidance from the NPS NSNSD. As a quantitative assessment of sky quality, NSNSD has related the synthetic SQM measurements to the corresponding Bortle classes (NPS 2015). Values > 21.3 were assigned to the *Resource in Good Condition* category; we values of 19.5–21.3 to the *Warrants Moderate Concern* category; and we assigned values < 19.5 to the *Warrants Significant Concern* category (Table 4.2.3).

Table 4.2.3. Night sky condition categories for the synthetic Sky Quality Meter (SQM).

Resource condition		
Condition Icon Definition	**Condition Icon**	**SQM values**
Warrants significant concern		< 19.5
Warrants moderate concern		19.5 – 21.3
Resource in good condition		> 21.3

<u>*Measure of Night Sky Quality: Sky Quality Index (SQI)*</u>

The Sky Quality Index (SQI) is a synthetic scale that identifies the amount of synthetic or artificial glow in the night sky. The SQI range is 0–100, where 100 is a dark sky free from artificial glow. Values of 80–100 are considered to be representative of skies that retain natural conditions throughout most of the sky (NPS 2015) and we assigned these values to the *Resource in Good Condition* category. Index values between 60–79 retain most of the visible natural sky features in areas above 40 degrees from the horizon, and we assigned these values to the *Warrants Moderate Concern* category. Ratings of 40–60 are areas where the Milky Way is not visible, or only slightly visible at zenith, 20–40 are skies in which only stars and planets are visible, and values 0–20 are skies where only the brightest stars are visible and a persistent twilight exists; we assigned ratings <60 to the *Warrants Significant Concern* category (Table 4.2.4).

Table 4.2.4. Night sky condition categories for the Sky Quality Index (SQI).

Resource condition		
Condition Icon Definition	**Condition Icon**	**SQI values**
Warrants significant concern		80 – 100
Warrants moderate concern		60 ≤ and < 80
Resource in good condition		< 60

Indicator: Natural Light Environment

Night skies are a unique resource that unify a human experience; throughout time, people have shared a similar experience when looking into a natural, dark sky. It is important to preserve this experience for current and future generations so that the opportunity to share a timeless experience is not lost. The natural nightscape, those resources that exist free from human caused light are critical for scenery, star viewing, and essential plant and wildlife functions (NPS 2012c). For these reasons, an important indicator to the Night Sky resource is the presence of natural nightscape and areas free from human caused light pollution.

Measure of Natural Light Environment: Anthropogenic Light Ratio (ALR)

Anthropogenic Light Ratio (ALR) is a measurement that compares the total night sky brightness to the value that would exist under completely natural conditions. This ratio can be measured directly, or modeled when data do not exist or are unavailable. A low ALR value indicates a night sky with low levels of anthropogenic light impacts. A ratio of 0.0 indicates completely natural conditions, while a ratio of 1.0 indicates that anthropogenic light is 100% brighter than that of a naturally dark (0.0) sky and a ratio of 5.0 indicates anthropogenic light 500% brighter than a sky in a naturally dark sky, for example.

Condition thresholds have been developed by the NSNSD and other researchers (Duriscoe et al. 2007, Moore et al. 2013, Manning et al. 2015), and are considered depending on the natural resources of the park. Parks with significant natural resources, like Agate Fossil Beds NM, are Level 1 parks with relatively low ALR condition thresholds compared to Level 2 parks with few natural resources, generally those situated in suburban and urban areas (Moore et al. 2013). Anthropogenic Light Rations with a value < 0.33 are representative of a generally natural state and were assigned to the category, *Resource in Good Condition*. Ratios of values 0.33–2.0 were assigned the condition, *Warrants Moderate Concern*, and any ALR values > 2.0 were considered severely degraded and assigned to the *Warrants Significant Concern* category (Table 4.2.5).

Table 4.2.5. Night sky condition categories for the Anthropogenic Light Ratio (ALR).

Resource condition		
Condition Icon Definition	**Condition Icon**	**ALR values**
Warrants significant concern	(red circle)	> 2.0
Warrants moderate concern	(yellow circle)	0.33 – 2.0
Resource in good condition	(green circle)	< 0.33

Data Sources

To assess the condition of night sky, we used data collected by NPS Natural Sounds and Night Skies Division. Data collection took place on July 16, 2006, September 2, 2008, September 26, 2008, and October 30, 2008; we used the most recent data, those collected on October 30, 2008. Data were collected on site at Agate Fossil Beds NM and included values for Bortle Class, Synthetic Sky Quality Meter (SQM), Sky Quality Index, and Anthropogenic Light Ratio (ALR).

Quantifying Night Sky Condition, Confidence, and Trend

Indicator Condition

We created condition categories based on NPS guidelines, expert opinion and the scientific literature. We used a point system to assign each indicator to a category. This point system is based on the NPS methods that were developed to calculate overall air quality condition (NPS 2015), a methodical and rigorous assessment approach that can be applied to other resources as well. In this approach, we assigned zero points to the condition *Warrants Significant Concern*, 50 points to *Warrants Moderate Concern*, and 100 points to *Resource in Good Condition*. The average of all measures determined the condition category of the indicator; scores from 0–33 fell in the *Warrants Significant Concern* category, scores from 34–66 were in the *Warrants Moderate Concern* category, and scores from 67–100 indicated *Resource in Good Condition*.

Indicator Confidence

Confidence ratings were based on availability of data collected about the indicator. We gave a rating of *High* confidence when data were collected by the Natural Sounds and Night Skies Division on site at the park unit. We assigned a *Medium* confidence rating when results were generated for a park unit using interpolated remote sensing data. When only less robust or no data were available, we assigned a Low confidence rating.

Indicator Trend

Potential trend categories were *Improving*, *Unchanging*, or *Deteriorating*. To calculate a trend estimate for indicators, we sought night sky data that were collected at least once in at least three different years and met the conditions for a *High* confidence rating. If there were no data available that met these monitoring requirements for a particular indicator, we indicated that trend was *Not Available* for that indicator.

Overall Night Sky Condition, Confidence, and Trend

We used the general approach for combining indicator conditions, trends, and confidence described in Chapter 3 (Methods 3.2.2) to calculate overall resource condition, trend, and confidence (Table 4.2.6).

Table 4.2.6. Summary of night sky indicators and measures.

Indicator	Measure	Condition	Confidence	Trend	Condition rationale
Night sky quality	Bortle Dark-Sky class	Resource in good condition	High	Not available	Bortle Dark-Sky class was 3, which placed the condition of this measure in the category, *Resource in Good Condition*. Monitoring was conducted on site but not frequently enough to identify a trend, so confidence was *High* and trend was *Not Available*.
	Synthetic Sky Quality Meter (SQM)	Resource in good condition	High	Not available	Average synthetic SQM was 21.46, which placed the condition of this measure in the category, Resource in Good Condition. Monitoring was conducted on site but not frequently enough to identify a trend, so confidence was High and trend was Not Available.
	Sky Quality Index (SQI)	Resource in good condition	High	Not available	SQI was 90.9, which placed the condition of this measure in the category, Resource in Good Condition. Monitoring was conducted on site but not frequently enough to identify a trend, so confidence was High and trend was Not Available.
Natural light environment	Anthropogenic Light Ratio (ALR)	Resource in good condition	High	Not available	ALR was 0.19, which placed the condition of this measure in the category Resource in Good Condition. Monitoring was conducted on site but not frequently enough to identify a trend, so confidence was High and trend was Not Available.

4.2.4. Night Sky Conditions, Confidence, and Trends

Night Sky Quality

Condition: Resource in Good Condition
Confidence: High
Trend: Not Available

Condition

The Bortle Dark Sky Class of 3, average Sky Quality Index of 90.9, and average Synthetic SQM or 21.46 all placed the condition of Night Sky Quality at Agate Fossil Beds NM in the category, *Resource in Good Condition*.

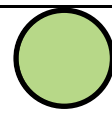
Confidence

Night Sky Quality data were collected by the NPS Natural Sounds and Night Skies Division conducted on site at Agate Fossil Beds NM, so confidence was *High*.

Trend

Data were not available for the minimum three years, so trend was *Not Available*.

<u>Natural Light Environment</u>



Condition: Resource in Good Condition
Confidence: High
Trend: Not Available

Condition

The average ALR rating of 0.19 at Agate Fossil Beds NM was in the category Resource in Good Condition. Anthropogenic Light Ratio was the only measure of the indicator, Natural Light Environment, so this indicator was in the category, *Resource in Good Condition*.

Confidence

Natural Light Environment data were collected by the NPS Natural Sounds and Night Skies Division conducted on site at Agate Fossil Beds NM, so confidence was *High*.

Trend

Data were not available for the minimum three years, so trend was *Not Available*.

<u>Night Sky Overall Condition</u>

Condition

The average score for all measures was 100, which placed the condition of night skies at Agate Fossil Beds NM in the category, *Resource in Good Condition* (Table 4.2.7).

Confidence

All data were collected by the NPS Natural Sounds and Night Skies Division conducted on site at Agate Fossil Beds NM, so confidence was *High*.

Trend

Data were not available for the minimum three years, so trend was *Not Available*.

Table 4.2.7. Night sky overall condition.

Indicators	Measures	Condition
Night sky quality	• Bortle Dark-Sky class • Synthetic Sky Quality Meter (SQM) • Sky Quality Index (SQI)	Good (green circle)
Natural light environment	• Anthropogenic Light Ratio (ALR)	Good (green circle)
Overall condition for all indicators and measures		Good (green circle)

4.2.5. Stressors

The night sky at Agate Fossil Beds is generally in very good condition. The greatest risk of light pollution is the community of Scottsbluff/Gering, about 45 miles to the south. Seasonally, an irrigation pivot operates to the east of Agate Fossil Beds BM; this pivot "has a fairly bright light mounted on it," that increases light levels within the park unit (A. Wilson, personal communication, 18 August 2016). Night sky experts in the park suggest that working with the rancher to change the color of the bulb could help limit this light source (A. Wilson, personal communication, 18 August 2016).

4.2.6. Data Gaps

The most recent data were collected in 2008, and no subsequent sampling has been conducted since. We were consequently unable to identify a trend in night sky condition. Annual or biennial (every two years) sampling of night sky conditions at Agate Fossil Beds NM would improve the ability of managers to maintain optimal night sky conditions.

Acknowledgments

- Anne Wilson (NPS)

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4.3. Soundscape/Acoustic Environment

The majority of the text in this section was written by the NPS Natural Sounds and Night Skies Division (NSNSD) to guide the NRCA process. We added details specific to give regional context for Agate Fossil Beds National Monument and reorganized several subsections to follow the structure that we used for the other NRCA natural resource sections.

Moonrise over Agate Fossil Beds NP (NPS photo).

4.3.1. Background and Importance

Our ability to see is a powerful tool for experiencing our world, but sound adds a richness that sight alone cannot provide. In many cases, hearing is the only option for experiencing certain aspects of our environment. An unimpaired acoustic environment is an important part of overall visitor experience and enjoyment as well as vitally important to overall ecosystem health.

Visitors to national parks often indicate that an important reason for visiting the parks is to enjoy the relative quiet that parks can offer. In a 1998 survey of the American public, 72% of respondents identified opportunities to experience natural quiet and the sounds of nature as an important reason for having national parks (Haas and Wakefield 1998). Additionally, 91% of NPS visitors "consider enjoyment of natural quiet and the sounds of nature as compelling reasons for visiting national parks" (McDonald et al. 1995).

Sound plays a critical role in intra- and inter-species communication, including courtship and mating, predation and predator avoidance, and effective use of habitat. Studies have shown that wildlife can be adversely affected by sounds that intrude on their habitats. While the severity of the impacts varies depending on the species being studied and other conditions, research strongly supports the fact that wildlife can suffer adverse behavioral and physiological changes from intrusive sounds (noise) and other human disturbances. Documented responses of wildlife to noise include increased heart rate, startle responses, flight, disruption of behavior, and separation of mothers and young (Selye 1956, Clough 1982, USDA 1992, Anderssen et al. 1993, NPS 1994).

The natural soundscape is an inherent component of "the scenery and the natural and historic objects and the wildlife" protected by the Organic Act of 1916. NPS Management Policies require the NPS to preserve the park's natural soundscape and restore the degraded soundscape to the natural condition wherever possible.

Additionally, NPS is required to prevent or minimize degradation of the natural soundscape from noise (i.e., inappropriate/undesirable human-caused sound). Although the management policies currently refer to the term soundscape as the aggregate of all natural sounds that occur in a park, differences exist between the physical sound sources and human perceptions of those sound sources. The physical sound resources (e.g., wildlife, waterfalls, wind, rain, and cultural or historical sounds), regardless of their audibility, at a particular location are referred to as the acoustic environment, while the human perception of that acoustic environment is defined as the soundscape. Clarifying this distinction will allow managers to create objectives for safeguarding both the acoustic environment and the visitor experience.

Regional Context

Agate Fossil Beds NM is surrounded by vast areas of prairie, with some agricultural development along the Niobrara River upstream and downstream of the park. Primary sources of non-natural sounds within the park include agricultural activities, automobile traffic on State Highway 29 and River Road, and air traffic passing overhead. Industrial activities and noise from business and heavily populated residential areas are unlikely to affect the acoustic environment in Agate Fossil Beds NM. The closest towns are Torrington, WY (population ~6,800), about 52 kilometers (32.5 miles) to the southwest of the park unit, and Mitchell, NE (population ~1,700), the same distance south of the park. The closest town with population > 10,000 is Scottsbluff, NE (population ~15,000), 60 kilometers (37 miles) to the south.

4.3.2. Soundscape/Acoustic Environment Standards

Sound Science 101

Humans and wildlife perceive sound as an auditory sensation created by pressure variations that move through a medium such as water or air. Sound is measured in terms of frequency and amplitude (Saunders et al. 1997, Harris 1998). Noise, essentially the negative evaluation of sound, is defined as extraneous or undesired sound (Morfey 2001).

Frequency, measured in Hertz (Hz), describes the cycles per second of a sound wave, and is perceived by the ear as pitch. Humans with normal hearing can hear sounds between 20 Hz and 20,000 Hz, and are most sensitive to frequencies between 1,000 Hz and 6,000 Hz. High frequency sounds are more readily absorbed by the atmosphere or scattered by obstructions than low frequency sounds. Low frequency sounds diffract more effectively around obstructions. Therefore, low frequency sounds travel farther.

Besides the pitch of a sound, we also perceive the amplitude (or level) of a sound. This metric is described in decibels (dB). The decibel scale is logarithmic, meaning that every 10 dB increase in sound pressure level (SPL) represents a tenfold increase in sound energy. This also means that small variations in sound pressure level can have significant effects on the acoustic environment. For instance, a 6 dB increase in a noise source will double the distance at which it can be heard, increasing the affected area by a factor of four. Sound pressure level is commonly summarized in terms of dBA (A-weighted sound pressure level). This metric significantly discounts sounds below 1,000 Hz and above 6,000 Hz to approximate human hearing sensitivity. Table 4.3.1 provides examples of A-weighted sound levels measured in national parks.

Table 4.3.1. Examples of sound levels measured in national parks (Ambrose and Burson 2004).

Decibel level (dBA)	Sound source	Park unit
10	Volcano crater	Haleakala NP
20	Leaves rustling	Canyonlands NP
40	Crickets at 5 m	Zion NP
60	Conversational speech at 5 m	Whitman Mission NHS
80	Snowcoach at 30 m	Yellowstone NP
100	Thunder	Arches NP
120	Military jet, 100m above ground level	Yukon-Charley Rivers NP
126	Cannon fire at 150m	Vicksburg NMP

The natural acoustic environment is vital to the function and character of a national park. Natural sounds (Table 4.3.1) include those sounds upon which ecological processes and interactions depend. Examples of natural sounds in parks include:

- Sounds produced by birds, frogs, or insects to define territories or attract mates
- Sounds produced by bats to navigate or locate prey
- Sounds produced by physical processes such as wind in trees, flowing water, or thunder

Although natural sounds often dominate the acoustic environment of a park, human-caused noise (Table 4.3.1) has the potential to mask these sounds. Noise impacts the acoustic environment much like smog impacts the visual environment; obscuring the listening horizon for both wildlife and visitors. Examples of human-caused sounds heard in parks include:

- Aircraft (e.g., high-altitude and military jets, fixed-wing, helicopters)
- Vehicles
- Generators
- Watercraft
- Grounds care (lawn mowers, leaf blowers)
- Human voices

Characterizing the Acoustic Environment

Oftentimes, managers characterize ambient conditions over the full extent of the park by dividing total area into “acoustic zones” on the basis of different vegetation zones, management zones, visitor use zones, elevations, or climate conditions. Then, the intensity, duration, and distribution of sound sources in each zone can be assessed by collecting sound pressure level (SPL) measurements, digital audio recordings, and meteorological data. Indicators typically summarized in resource assessments include natural and existing ambient sound levels and types of sound sources. Natural ambient sound level refers to the acoustical conditions that exist in the absence of human-caused noise and represents the level from which the NPS measures impacts to the acoustic environment. Existing ambient sound level refers to the current sound intensity of an area, including both natural and human-caused sounds.

The influence of anthropogenic noise on the acoustic environment is generally reported in terms of SPL across the full range of human hearing (12.5–20,000 Hz), but it is also useful to report results in a much narrower band (20–1250 Hz) because most human-caused sound is confined to these lower frequencies.

Reference Conditions

Reference criteria should address the effects of noise on human health and physiology, the effects of noise on wildlife, the effects of noise on the quality of the visitor experience, and finally, how noise impacts the acoustic environment itself.

Various characteristics of sound can contribute to how noise may affect the acoustic environment. These characteristics may include rate of occurrence, duration, amplitude, pitch, and whether the sound occurs consistently or sporadically. In order to capture these aspects, the quality of the acoustic environment is assessed using a number of different metrics including existing ambient and natural ambient sound level (measured in decibels), percent time human-caused noise is audible, and noise-free interval. In summary, if we are to develop a complete understanding of a park's acoustic environment, we must consider a variety of sound metrics. This can make selecting one reference condition difficult. For example, if we chose to use just the natural ambient sound level for our reference condition, we would focus only on sound pressure level and overlook the other aspects of sound mentioned above.

Ideally, reference conditions would be based on measurements collected in the park, but this is not always logistically feasible. In cases where on-site measurements have not been gathered, one can reference meta-analyses of national park monitoring efforts. Aggregated data from 189 sites in 43 national parks (Lynch et al. 2011) had a median L_{90} across all sites and hours of the day of 21.8 dBA (between 20 and 800 Hz). L_{90} is the sound level that is heard 90% of the time; an estimate of the background against which individual sounds are heard. A similarly comprehensive geospatial modeling effort (Mennitt et al. 2013) assimilated data from 291 park monitoring sites across the nation, revealing that the median daytime existing sound level in national parks rested around 31 dBA. In addition, among 89 acoustic monitoring deployments analyzed for audibility, the median percent time audible of anthropogenic noise during daytime hours was found to be 35%.

4.3.3. Methods

Using acoustic data collected at 244 sites and 109 spatial explanatory layers (such as location, landcover, hydrology, wind speed, and proximity to noise sources such as roads, railroads, and airports), NSNSD developed a geospatial sound model that predicts natural and existing sound levels with 270-meter resolution (Figure 4.3.1, Mennitt et al. 2013).

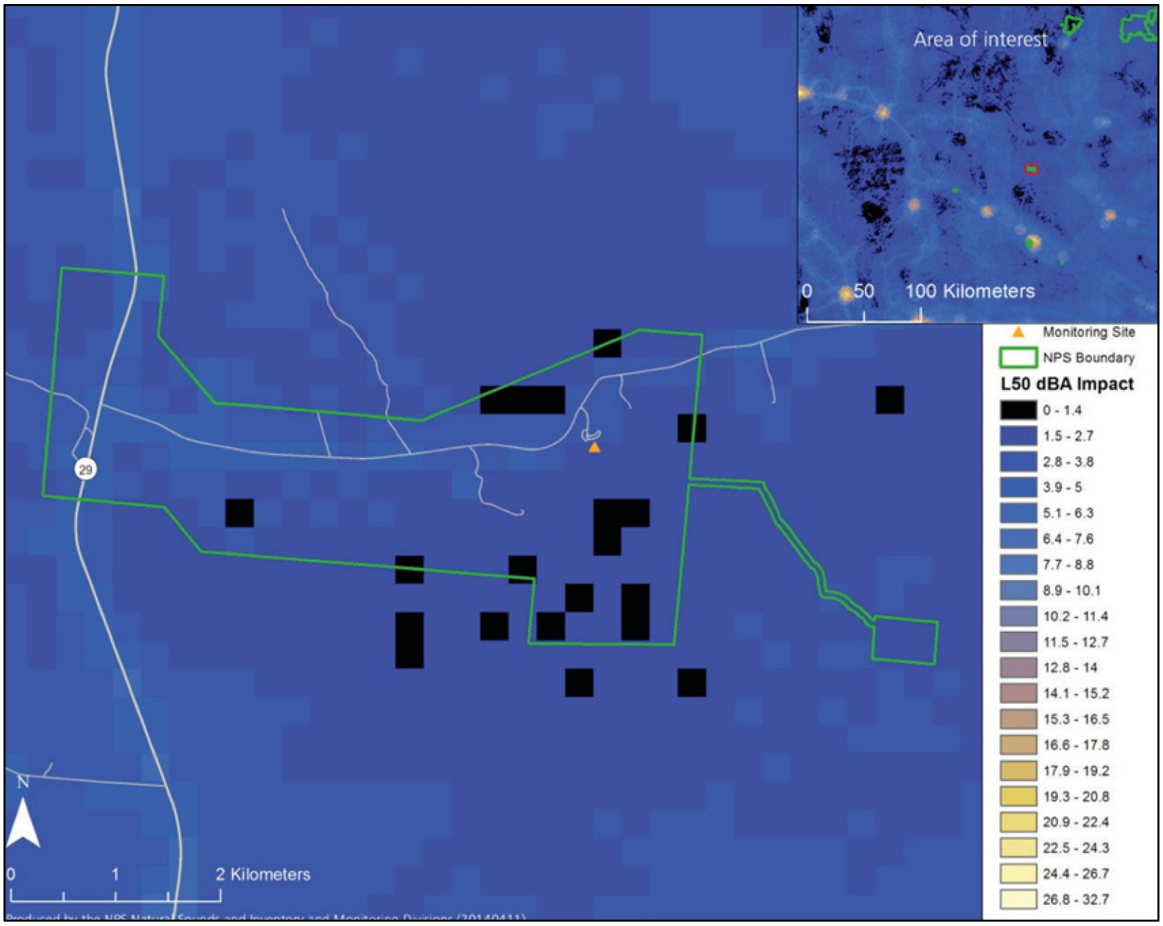

Figure 4.3.1. Modeled L_{50} dBA impact levels in Agate Fossil Beds National Monument (NPS).

Indicators and Measures

We assessed overall acoustic environment condition using a single indicator: anthropogenic impact. To assign a condition to this indicator, we used a measurement identified by the NPS Natural Sounds and Night Skies Division. Potential conditions were: *Resource in Good Condition*, *Warrants Moderate Concern*, and *Warrants Significant Concern*.

Indicator: Anthropogenic Impact

The soundscape of a park is the totality of the perceived acoustical environment. Soundscape usually refers to human perception, but the term could also apply to other species. For example, bat soundscapes include a wealth of ultrasonic information that is not represented in human soundscapes. Park soundscapes, and park acoustical environments, will often include noise from sources inside and outside the park boundaries. Noise is unwanted sound, whereas extraneous sound serves no function. Much noise comes from anthropogenic sources, so identifying the extent of these sources on the acoustic environment can reveal potential impacts to wildlife and to visitor experience.

Measure of Anthropogenic Impact: L_{50} dBA Impact (Existing Ambient Sound – Natural Ambient Sound)

In addition to predicting existing and natural ambient sound levels, the geospatial model developed by the NPS Natural Sounds and Night Skies Division also calculates the difference between the two metrics. This difference is a measure of impact to the natural acoustic environment from anthropogenic sources. The resulting metric (L_{50} dBA impact) indicates how much anthropogenic noise raises the existing sound pressure levels in a given location. Specifically, L_{50} is the median sound level attributable to anthropogenic sources that is exceeded ≥ 50% of time in a summer day.

Because the National Park System comprises a wide variety of park units, two threshold categories (Table 4.3.2) are generally considered (urban and non-urban), based on proximity to urban areas (U.S. Census Bureau 2010). The urban criteria are applied to park units that have at least 90% of the park property within an urban area. The non-urban criteria are applied to units that have at least 90% of the park property outside an urban Area. Parks that are distant from urban areas possess lower sound levels, and they exhibit less divergence between existing sound levels and predicted natural sound levels. These quiet areas are more susceptible to subtle noise intrusions than urban areas. Visitors to parks have expectations for noise-free environments within their listening area, the area in which they can perceive sound (NPS 2015). Accordingly, the thresholds for *Warrants Moderate Concern* and *Warrants Significant Concern* ratings are lower for these park units than for units near urban areas.

Table 4.3.2. Soundscape/acoustic environment condition categories for anthropogenic impact. Agate Fossil Beds NM is a non-urban park, so condition was evaluated using the non-urban criteria.

Resource condition		Mean L_{50} impact (dBA) non-urban
Condition Icon Definition	**Condition Icon**	
Warrants significant concern		dBA > 3.0 Listening area reduced by > 50%
Warrants moderate concern		1.5 < dBA ≤ 3.0 Listening area reduced by 30–50%
Resource in good condition		dBA ≤ 1.5 Listening area reduced by ≤ 30%

Measure of Anthropogenic Impact: Qualitative Assessment

While quantitative modeled sound data provide a general picture of noise issues within a park, models may miss sounds that are seasonal and/or not directly connected to standard sources of noise (e.g., airports, highways, industrial facilities). We relied on expert opinion among park management to validate the modeled soundscape and to identify additional sources of noise, when relevant.

Data Sources

We used predicted sound level data collected by NPS Natural Sounds and Night Skies Division to identify mean impact levels in Agate Fossil Beds NM.

Quantifying Soundscape/Acoustic Environment Condition, Confidence, and Trend

To quantify soundscape condition and trend, we used assessment criteria developed by the NPS Natural Sounds and Night Skies Division (Turina et al. 2013).

Indicator Confidence

Confidence ratings were based on availability of data collected about the indicator. We gave a rating of *High* confidence when data were collected using methods approved by the NPA Natural Sounds and Night Skies Division. We assigned a *Medium* confidence rating when data were collected for short periods of time or did not differentiate between ambient natural and ambient existing sounds, and assigned *Low* confidence ratings when acoustic data were unavailable.

Indicator Trend

Potential trend categories were *Improving*, *Unchanging*, or *Deteriorating*. To calculate a trend estimate for indicators, we required data that were collected on-site or interpolated using geospatial modeling for multiple years. If there were no data available that met these monitoring requirements, we indicated that trend was *Not Available* for that indicator.

Evaluating trends in condition is straightforward for parks where repeated measurements have been conducted because measurements can be compared. But inferences can also be made for parks where fewer data points exist. Nationwide trends indicate that prominent sources of noise in parks (namely vehicular traffic and aircraft) are increasing. However, it is possible that conditions in specific parks differ from national trends. The following events might contribute to a declining trend in the quality of the acoustic environment: expansion of traffic corridors nearby, increases in traffic due to industry, changes in zoning or leases on adjacent lands, changes in land use, planned construction in or near the park, increases in population, and changes to airspace (particularly those which bring more aircraft closer to the park). Most states post data on traffic counts on department of transportation websites, and these can be a good resource for assessing trends in vehicular traffic. Changes to airport operations, air space, and land use will generally be publicized and evaluated through the National Environmental Policy Act (NEPA) process.

Conversely, the following events may signal improvements in trend: installation of quiet pavement in or near parks, use of quiet technology for recreation in parks, decrease in vehicle traffic, use of quiet shuttle system instead of passenger cars, building utility retrofits (e.g. replacing a generator with solar array), or installation of “quiet zone” signage.

Overall Soundscape/Acoustic Environment Condition, Confidence, and Trend

We used only one indicator, so the condition, confidence and trend of the indicator were also the overall condition, confidence, and trend.

4.3.4. Soundscape/Acoustic Environment Conditions, Confidence, and Trends

Soundscape/Acoustic Environment Overall Condition

Condition

The L_{50} dBA impact level at Agate Fossil Beds NM was 1.1, which placed overall condition for soundscape at Agate Fossil Beds NM in the category, *Resource in Good Condition* (Table 4.3.3). Park staff and managers agreed that this overall assessment was reasonable.

Confidence

We used methods developed by NPS NSNSD to assess soundscape condition, and used data supplied by the division to complete the assessment. The confidence was *High*.

Trend

Acoustic data for Agate Fossil Beds NM were insufficient to calculate a trend. Trend was *Not Available.*

Table 4.3.3. Soundscape/acoustic environment overall condition.

Indicators	Measures	Condition
Anthropogenic impact	• L_{50} dBA impact • Qualitative assessment	(green circle)

4.3.5. Stressors

A common source of noise in national parks is transportation (e.g., airplanes, vehicles). Growth in the number of vehicles on the road is increasing faster than is the human population in the US (Barber et al. 2010). Between 1970 and 2007, traffic on US roads nearly tripled to almost 5 trillion vehicle kilometers/year (http://www.fhwa.dot.gov/ohim/tvtw/tvtpage.cfm). Aircraft traffic grew by a factor of three or more between 1981 and 2007 (http://www.bts.gov/programs/airline_information/air_carrier_traffic_statistics/airtraffic/annual/198_present.html). As these noise sources increase throughout the United States, the ability to protect pristine and quiet natural areas becomes more difficult (Mace et al. 2004).

Potential stressors included vehicle traffic passing by the park on the main road, air traffic overhead, and cattle herding during certain times of year. While automobile traffic in and around Agate National Fossil Beds NM is currently low volume, visitor traffic in the future could affect the soundscape were these volumes to increase. Air traffic noise could likewise increase, and may be a more consistent source of noise than automobiles; while park hours and visitor travel patterns may limit the times during which a park experiences heightened sound impact, air traffic will be less sensitive to these patterns.

4.3.6. Data Gaps

Baseline acoustic ambient data collection will clarify existing conditions and provide greater confidence in resource condition trends. Wherever possible, baseline ambient data collection should be conducted. In addition to providing site specific information, this information can also strengthen the national noise model.

With respect to the effects of noise, there is compelling evidence that wildlife can suffer adverse behavioral and physiological changes from noise and other human disturbances, but the ability to translate that evidence into quantitative estimates of impacts is presently limited. Several recommendations have been made for human exposure to noise, but no guidelines exist for wildlife and the habitats we share. The majority of research on wildlife has focused on acute noise events, so further research needs to be dedicated to chronic noise exposure (Barber et al. 2011). In addition to wildlife, standards have not been developed yet for assessing the quality of physical sound resources (the acoustic environment), separate from human or wildlife perception. Scientists are also working to differentiate between impacts to wildlife that result from the noise itself or the presence of the noise source.

Acknowledgments

- Emma Brown (NPS)

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4.4. Air Quality

4.4.1. Background and Importance

Most visitors expect clean air and clear views in parks. However, air pollution can sometimes affect Agate Fossil Beds NM. Clean, clear air is critical to human health, the health of ecosystems, and the appreciation of scenic views. Pollution can damage animal health (including human health), plants, water quality, and alter soil chemistry (e.g., Heagle et al. 1973, Schulze 1989, Brunekreef and Holgate 2002). Our ability to clearly see color and detail in distant views (visibility) can also be impacted by air pollution.

Clear skies above the Fossil Hills (NPS photo).

The National Park Service (NPS) is dedicated to preserving natural resources, including clear air. The National Park Service Organic Act (16 USC § 1 1916) and the Clean Air Act (CAA; 42 USC § 7401et seq. 1970) codify this commitment, specifying that NPS protect air quality within park units for the integrity of other natural and cultural resources.

The Clean Air Act designates three classes (Class I, II, and III) of air quality protection, and the U.S. Environmental Protection Agency (EPA) sets National Ambient Air Quality Standards (NAAQS) for acceptable pollutant levels within these classes. Class I airsheds have the strictest regulations, but all three classes are regulated to specific levels to protect and improve national air quality (42 USC § 7401 et seq. 1970). Park units smaller than 6,000 acres in area, including Agate Fossil Beds NM, are typically Class II airsheds.

These protective classifications mean that NPS units receive federal assistance to protect and improve their air quality, but regulation within park boundaries may not be enough. Many of the threats to clean air in NPS units come from pollution sources outside of park boundaries (Ross 1990). As a result, protection and improvement of air quality within parks require active NPS participation and cooperative conservation partnerships with air regulatory agencies, stakeholders, and other federal land managers. The CAA makes a provision for federal land managers to participate in regulatory decision-making when protected federal lands, such as NPS units, may be affected (Ross 1990). Participation may include consultations, written comments, recommendations, and review.

Regional Context
Most emissions that contribute to air pollution have declined substantially in the U.S. since 1970 despite population and economic growth (Figure 4.4.1), but current air quality conditions are mixed across states and regions (ALA 2015).

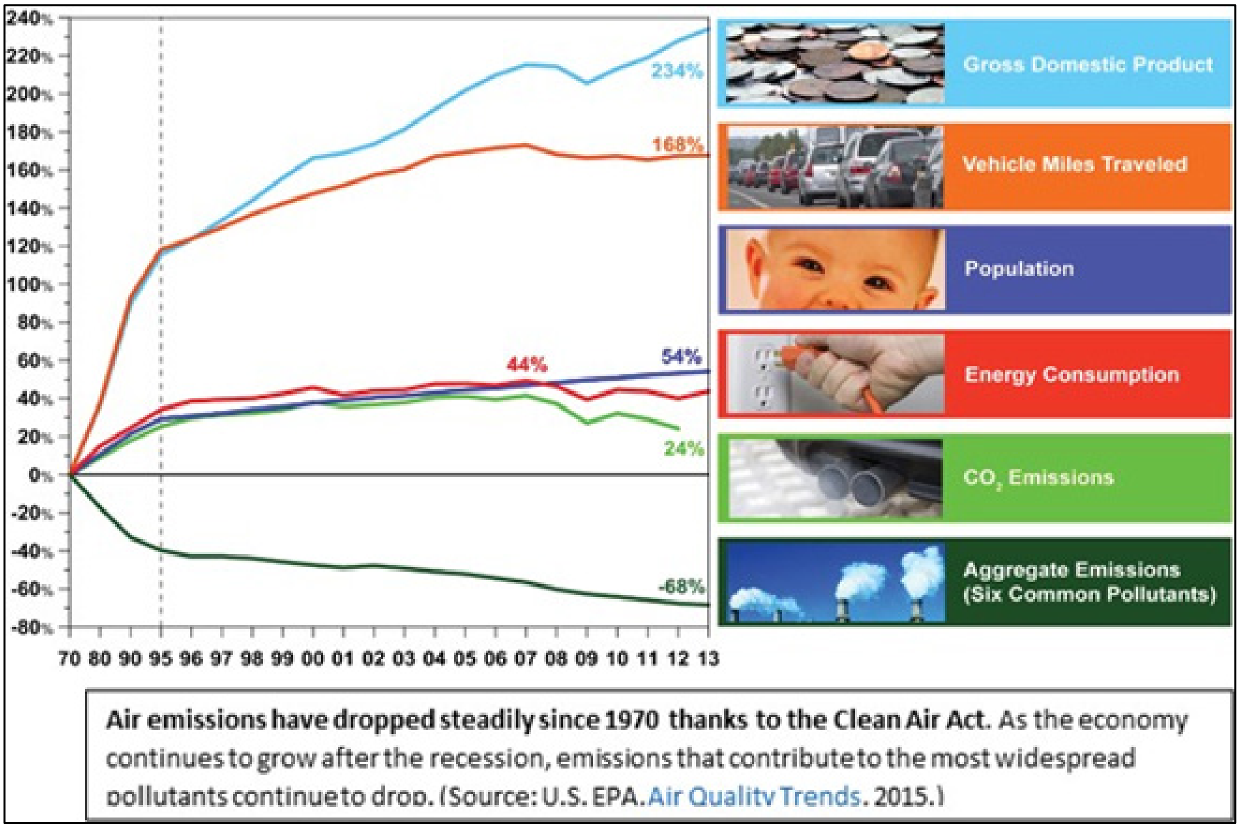


Figure 4.4.1. Air quality trends for the United States from 1970 to 2013. Emissions that contribute to poor air quality in the United States have declined substantially since 1970, in spite of economic and population growth (Figure courtesy of EPA http://www.epa.gov/airtrends/aqtrends.html#comparison).

The American Lung Association compiles a State of the Air report for each state, and assigns grades for air quality by county. Agate Fossil Beds NM is located in Sioux County where there were not enough monitoring data from 2013–2015 to assign a grade for ozone pollution or particle pollution (ALA 2015); adjacent Scotts Bluff county, to the south, received a B (second best grade) for ozone during that time period, and an A (best grade) for short-term particle pollution. Three of Nebraska's 93 counties had sufficient data for the ALA to assign an overall grade to ozone pollution, and only six counties received a grade for particle pollution; the grades ranged from A to C, indicating heterogeneity in air quality.

Coal fired power plants, vehicle exhaust, oil and gas development, agriculture, and fires are contributors to regional air quality. Since 2000, emissions from regional coal-fired power plants have decreased with further reductions anticipated over the next few years. Emissions from regional oil and gas are likely to increase.

4.4.2. Air Quality Standards

A variety of pollution sources can degrade air quality. Primary pollutants, such as gasses from fossil fuel combustion, wildfires, dust storms, and volcanic eruptions, are emitted directly from a source. Secondary pollutants are indirect, forming when primary pollutants react with natural compounds in the atmosphere. Examples of secondary pollutants include nitrogen dioxide (NO_2) and other nitrogen oxide compounds (NO_x), ozone (O_3), and sulfuric acid (H_2SO_4). Some polluting sources may contribute both primary and secondary pollutants. For example, coal-powered plants produce SO_2, NO_x, particulate matter, and mercury.

The EPA sets standards at levels specific to protecting human and environmental health (40 CFR part 50). Primary standards are set to protect public health, and slightly less stringent secondary standards are set to safeguard animals, plants, structures, and visibility (EPA 2016a). The NPS Air Resources Division uses the EPA's standards, natural visibility goals, and ecological thresholds as benchmarks to assess current conditions of visibility, ozone, and atmospheric deposition throughout parks.

4.4.3. Methods

Indicators and Measures

The approach used for assessing the condition of air quality parameters at the park was developed by the NPS Air Resources Division (NPS-ARD) for use in Natural Resource Condition Assessments (NPS-ARD 2015b). Overall air quality condition was assessed with six main indicators (Figure 4.4.2):

- Visibility
- Ozone
- Particulate matter
- Nitrogen deposition
- Sulfur deposition
- Mercury deposition

Each of these indicators contributes to different aspects of air quality and can affect human and environmental health in different ways.

To assign a condition to each indicator, we used measurements specified by NPS-ARD and EPA (NPS-ARD 2013, EPA 2014, NPS-ARD 2015a). Measurements were compared to benchmarks recommended by NPS-ARD and EPA to assign one of three condition categories: *Resource in Good Condition*, *Warrants Moderate Concern*, and *Warrants Significant Concern*. We used additional measurements to support the indicator condition, and then considered all indicator conditions together in an overall air quality condition assessment.

Some lichens (see "Lichens and Air Quality" section below) and plants that are sensitive to air quality conditions may provide an additional qualitative measure of overall air quality. However, because the effects of air quality are not easily teased apart from other environmental conditions that affect flora, lichen presence is best used in conjunction with quantitative measures (NPS-ARD 2015a).

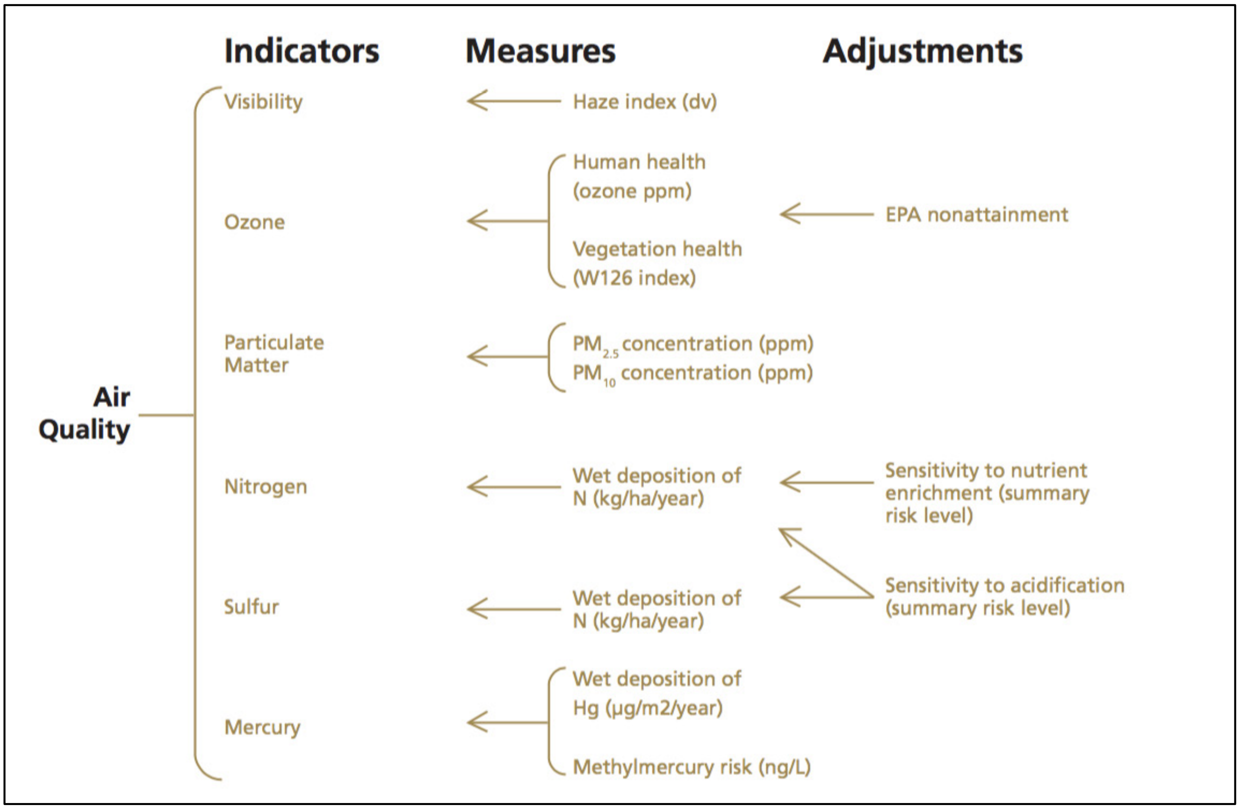


Figure 4.4.2. Schematic of the factors considered in air quality condition assessment.

Lichens and Air Quality

Lichens have long been promoted as good indicators of air pollution because 1) lichens concentrate a variety of pollutants in their tissues, 2) pollutants can cause adverse physiological changes in some lichen species, and 3) biomonitoring is less expensive than traditional air quality monitoring with specialized equipment (Pohlman and Maniero 2005).

Unlike air quality monitors that collect data on individual pollutants, the presence and condition of specific lichens can indicate a cumulative biological response to air quality. Some lichens are sensitive to pollutants—particularly N and S—and others are tolerant of poor air quality conditions (e.g. Brodo et al. 2001). The presence of sensitive lichens can be a sign of good air quality in the area, but their absence is not necessarily due to poor air quality. Lichens can be affected by many stressors besides air pollution (e.g., climate change, grazing, habitat alterations, and fire), so it is difficult to establish a cause-and-effect relationship between air quality and lichen health. Therefore, studies to document current or potential future impacts on lichens are most effective when used in conjunction with other data.

There are a number of lichens at Agate Fossil Beds NM that have been rated in their sensitivity to air pollution (Table 4.4.1). Monitoring these species over time could be a valuable addition to the park's understanding of the cumulative effects of air pollution.

Table 4.4.1. Lichen species at Agate Fossil Beds NM with known level of sensitivity. S= sensitive, I=intermediate sensitivity T=tolerant.

Species name	Sensitivity
Physcia adscendens	I
Caloplaca holocarpa	I
Caloplaca vitellinula	I–T
Lecanora dispersa	T
Lecanora muralis	T
Physcia dubia	T

Indicator: Visibility

Visibility—how well and how far a person can see—can affect visitor experience. Both particulate matter (e.g., soot and dust) and certain gases and particles in the atmosphere, such as sulfate and nitrate particles, can create haze and reduce visibility (Figure 4.4.3). At night, air pollution scatters artificial light, increasing the effect of light pollution. Visitors expecting to see particular vistas may be disappointed by reduced visibility. Haze can degrade visibility by up to 60% relative to baseline conditions in western parks (EPA 2015a). On the clearest days at Badlands NP, the visibility is about 140 miles, which approaches the 180-mile visual range seen under natural conditions (IMPROVE 2016). However, sometimes hazy days occur when the visibility is only about 55 miles.

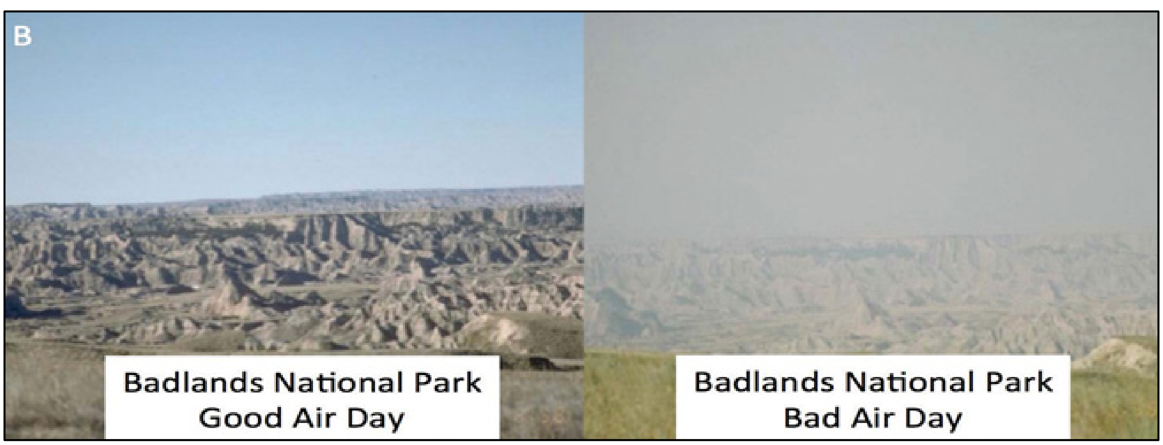


Figure 4.4.3. Photo representation of air quality in Badlands NP for a good air and bad air day. Haze can reduce visibility at Fort Laramie NHS and may be accompanied by an increased risk to human and environmental health. Fires and dust storms can contribute to poor air quality days, such as this one at Badlands NP (Photo by NPS-ARD 2015c; http://www.nature.nps.gov/air/WebCams/index.cfm).

Measure of Visibility: Haze Index

The CAA established a national goal to return visibility to "natural conditions" in Class I areas and the NPS-ARD recommends a visibility benchmark condition for all NPS units, regardless of Class designation, consistent with the Clean Air Act goal. Natural visibility conditions are those estimated to exist in a given area in the absence of human-caused visibility impairment. The Regional Haze Rule (40 CFR § 51–52 1999) calls for improving the worst air quality days and preventing degradation on good air quality days. The haze index (measured in deciviews [dv]) is used to track regional haze. The deciview scale scores pristine conditions as a zero and increases as visibility decreases. Agate Fossil Beds NM is not a Class I airshed, and therefore not subject to the rule, but the rule provides a good measurement protocol that is relevant to a park for which air quality is an important consideration.

NPS-ARD assesses visibility condition based on the deviation of the estimated current visibility on mid-range days from natural visibility conditions (i.e., those estimated for a given area in the absence of human-caused visibility impairment). Mid-range days are defined as the mean of the visibility observations falling within the range of the 40th through the 60th percentiles and are expressed in terms of a haze index. The visibility condition is calculated as follows:

Visibility Condition = estimated current haze index on mid-range days – estimated haze index under natural conditions on mid-range days

For visibility condition assessments, annual haze index measurements on mid-range visibility days are averaged over a 5-year period at each visibility monitoring site with at least three years of complete annual data and interpolated across all monitoring locations for the contiguous U.S. The maximum value within the Agate Fossil Beds NM boundary is reported as the visibility condition from this national analysis and compared to NPS-ARD benchmarks (Table 4.4.2).

Table 4.4.2. Air quality condition categories for visibility (NPS-ARD 2015a).

Resource condition		
Condition Icon Definition	**Condition Icon**	**Visibility* (dv)**
Warrants significant concern	Red circle	> 8
Warrants moderate concern	Yellow circle	2 – 8
Resource in good condition	Green circle	< 2

* Estimated 5-year average of visibility on mid-range days minus natural condition of mid-range days.

Visibility is monitored through the Interagency Monitoring of Protected Visual Environments (IMPROVE) Program. In this assessment, we relied primarily on NPS-ARD air quality trends (2004–

2013) and conditions (2009–2013; NPS-ARD 2015b), with reference to additional studies and data where relevant.

A visibility condition estimate of less than 2 dv above estimated natural conditions indicates that air quality is in *Good Condition*, estimates ranging from 2–8 dv above natural conditions *Warrant Moderate Concern*, and estimates greater than 8 dv above natural conditions *Warrant Significant Concern*. Reference condition ranges reflect the variation in visibility conditions across the monitoring network.

Visibility trends were computed from haze index values on the 20% haziest days and the 20% clearest days, consistent with visibility goals in the Clean Air Act and Regional Haze Rule, which include improving visibility on the haziest days and allowing no deterioration on the clearest days. If the haze index trend on the 20% clearest days is deteriorating, the overall visibility trend is reported as deteriorating. Otherwise, the haze index trend on the 20% haziest days is reported as the overall visibility trend. Visibility trends were calculated from the monitor located at Wind Cave National Park.

Indicator: Ozone

Ozone (O_3) is a colorless gas that naturally occurs high in the atmosphere and protects the earth's surface from harmful ultraviolet rays. However, ozone that occurs close to the ground can be harmful to animal and plant health (McKee 1994, Sokhi 2011). Ground-level ozone is a secondary pollutant that is formed when oxygen reacts with nitrogen oxides (NO_x), volatile organic compounds (VOCs), or carbon monoxide (CO) in the presence of sunlight. On hot, sunny days, the right combination of these compounds can combine to form ozone (Figure 4.4.4).

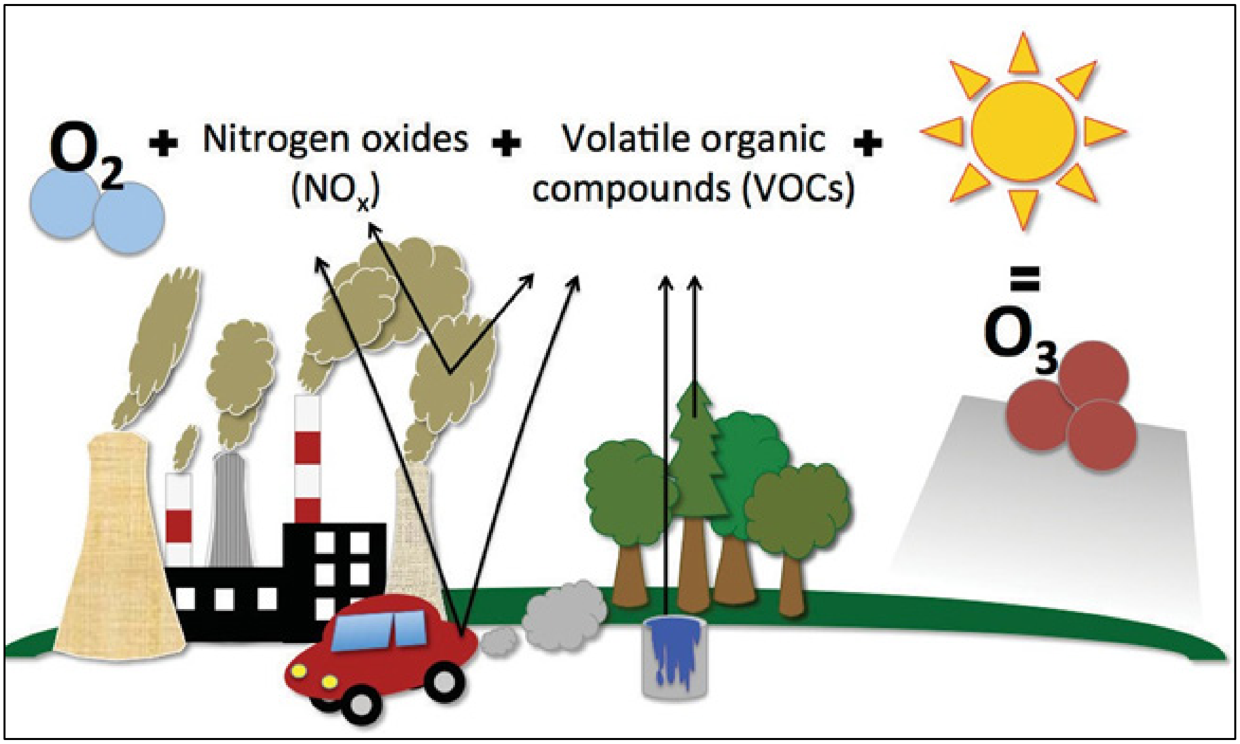


Figure 4.4.4. Graphic illustrating ozone (O_3) production (Dibner 2017). Ozone is formed when oxygen (O_2) combines with nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in the presence of sunlight. Fuel combustion from vehicles, power plants, and industrial operations produces NO_x and VOCs. Additional VOCs are produced by anthropogenic sources, such as paints and other solvents, and natural sources, like plants. Ground level ozone can be hazardous to human and environmental health (NPS-ARD 2015b).

While VOCs are produced naturally by some plants and soil microbes (Insam and Seewald 2010), additional VOCs are emitted room chemical solvents and during fuel combustion (EPA 2015b). Nitrogen oxides are produced by burning fossil fuels, and the largest sources of NO are industrial and vehicle emissions.

Ozone pollution has generally decreased in the United States since 1980 and, to a lesser extent, in the Northern Rockies and Plains region as well (EPA 2014b). In South Dakota, vehicle emissions produce the majority of NO_x, followed by biogenics, non-vehicle fuel combustion, and industrial fires (EPA 2015c). At monitoring sites close to South Dakota, there was little change in ozone concentration from 2001–2007 (Figure 4.4.5).

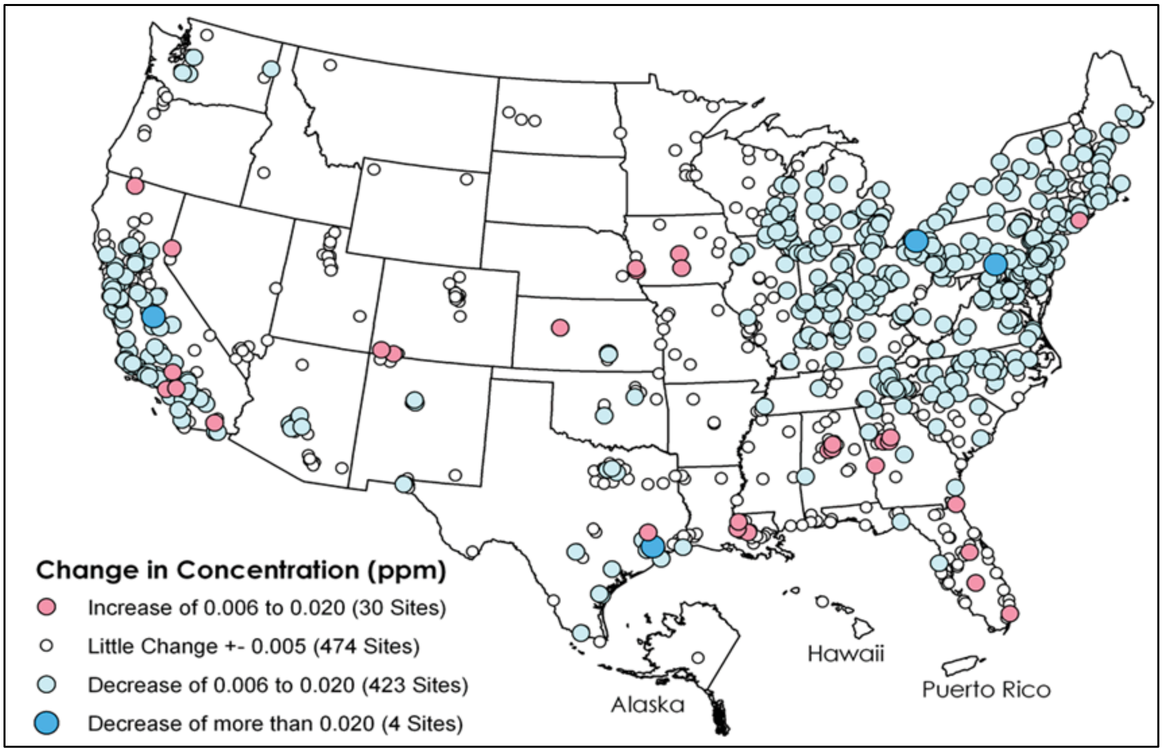


Figure 4.4.5. Change in ozone concentrations from 2001 to 2007 (EPA 2008).

Measure of Ozone: Human Health - Ozone Concentration (4th-Highest Daily Maximum 8-Hour Ozone Concentration in Parts per Billion [ppb])

The primary standard for ground-level ozone is based on human health effects. The status for human health risk from ozone is assessed using the 4th-highest daily maximum 8-hour ozone concentration in parts per billion (ppb). Ozone is monitored across the U.S. through air quality monitoring networks operated by the NPS, EPA, states, and others. Annual ozone concentrations were averaged over a 5-year period at all monitoring sites and interpolated for the contiguous U.S. The ozone condition for human health risk at Agate Fossil Beds NM was based upon the maximum estimated value within the monument boundary derived from this national analysis.

To assign a condition to the human health measure of ozone, we used the results from the NPS-ARD report on condition and trends for ozone (NPS-ARD 2015b) from 2009–2013. The NPS-ARD rates ozone condition as *Resource in Good Condition* if the ozone concentrations are less than 54 ppb *Warrants Moderate Concern* if the ozone concentration is between 55 and 70 ppb, and of *Warrants Significant Concern* if the concentration is greater than or equal to 71 ppb (Table 4.4.3).

Table 4.4.3. Air quality condition categories for human health ozone condition (NPS-ARD 2015a).

Resource condition		Ozone concentration* (ppb)
Condition Icon Definition	**Condition Icon**	
Warrants significant concern	Red circle	≥ 71
Warrants moderate concern	Yellow circle	55 – 70
Resource in good condition	Green circle	≤ 54

* Estimated or measured five-year average of annual 4th-highest daily maximum 8-hour.

Condition Adjustment: Ozone

If the NPS unit is located in an area that the EPA designates as "nonattainment" for the 75 ppb ground-level ozone standard, then the ozone condition automatically becomes *Warrants Significant Concern* (NPS-ARD 2015a). We referred to the EPA Air Trends (EPA 2014b) reports to identify locations designated as nonattainment for ground-level ozone.

Measure of Ozone: Vegetation Health – W126 Index

Ozone can damage plants (Figure 4.4.6), and some species are particularly sensitive to ozone damage. Ozone-sensitive plant species can be used as bioindicators (Kohut 2007) to assess ozone levels at a park unit. Ozone penetrates leaves through stomata (openings) and oxidizes plant tissue, which alters physiological and biochemical processes. Once the ozone is inside the plant's cellular system, chemical reactions can cause cell injury or even death, but more often reduce resistance to insects and diseases, growth, and reproductive capability.

The extent of foliar damage is influenced by several factors, including the sensitivity of the plant to ozone, the level of ozone exposure, and the exposure environment (e.g., soil moisture). The highest ozone risk exists when the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and environmental conditions, particularly soil moisture, foster gas exchange and the uptake of ozone by plants (Kohut 2004).

Figure 4.4.6. Foliar damage caused by high ambient levels of ozone (Photo by USDA ARS).

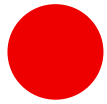
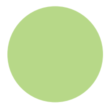
Exposure indices are biologically relevant measures used to quantify plant response to ozone exposure. These measures are better predictors of vegetation response than the metric used for the human health standard. The NPS-ARD assesses vegetation health risk from ozone condition with the W126 index, which preferentially weights the higher ozone concentrations most likely to affect plants and sums all of the weighted concentrations during daylight hours. The highest 3-month period that occurs during the ozone season is reported in parts per million-hours (ppm-hrs).

Ozone is monitored across the U.S. through air quality monitoring networks operated by the NPS, EPA, states, and others. Annual maximum W126 values were averaged over a 5-year period at all monitoring sites with at least 3 years of complete annual data and interpolated for the contiguous U.S. The ozone condition for vegetation health risk at Agate Fossil Beds NM was based upon the maximum value within the monument boundary derived from this national analysis.

To assign a condition for the vegetation health measure of ozone, we used results from the NPS-ARD report on condition and trends for ozone (NPS-ARD 2015b) from 2009–2013.

The W126 condition thresholds are based on information in EPA's Policy Assessment for the Review of the Ozone National Ambient Air Quality Standards (EPA 2014). Research has found that for a W126 value of ≤ 7 ppm-hrs, tree seedling biomass loss is ≤ 2 % per year in sensitive species. For W126 ≥ 13 ppm-hrs, tree seedling biomass loss is 4–10 % per year in sensitive species. NPS-ARD recommends a W126 of < 7 ppm-hrs to protect most sensitive trees and vegetation. A W126 index in this range was assigned *Resource in Good Condition*, a W126 index of 7–13 *Warrants Moderate Concern* condition, and an index > 13 *Warrants Significant Concern* (NPS-ARD 2015a; Table 4.4.4).

Table 4.4.4. Air quality condition categories for vegetation health ozone condition (NPS-ARD 2015a).

Resource condition		W126* (ppm-hrs)
Condition Icon Definition	**Condition Icon**	
Warrants significant concern		> 13
Warrants moderate concern		7 – 13
Resource in good condition		< 7

* Estimated or measured 5-year average of the maximum 3-month 12-hour W126.

Indicator: Particulate Matter

Particulate matter can be detrimental to visibility and human health. There are two particle size classes of concern: $PM_{2.5}$ – fine particles found in smoke and haze, which are 2.5 micrometers in diameter or less; and PM_{10} – coarse particles found in wind-blown dust, which have diameters between 2.5 and 10 micrometers. Both sizes can cause inflammation and irritation of the respiratory system in humans. People can be more susceptible to health effects from air pollution when they are engaged in strenuous recreation. Particulate matter of different sizes can have different consequences for public and ecosystem health (Stözel et al. 2007, EPA 2009). The standard for particulate matter is set by the EPA, and is based on human health effects.

Measure of Particulate Matter: $PM_{2.5}$ Concentration

The $PM_{2.5}$ primary standard is 12 micrograms per cubic meter ($\mu g/m^3$) annually (3-year average of weighted annual mean) and 35 g/m^3 for 24-hours (3-year average of the 98th percentile of 24-hour concentrations). Fine particulate matter ($PM_{2.5}$) data were collected from 2003–2011 in Sioux County, Nebraska. We evaluated these data over the most recent three years of the sampling period. NPS units that are in EPA designated nonattainment areas for particulate matter are assigned Warrants Significant Concern condition for particulate matter. For NPS units that are outside particulate matter nonattainment areas, EPA AQI breakpoints were used to assign a particulate matter condition based on 3-year average of the 98th percentile of 24-hour $PM_{2.5}$ concentrations (Table 4.4.5).

Table 4.4.5. Air quality condition categories for particulate matter.

Resource condition		98th Percentile 24-hour $PM_{2.5}$ concentration* (µg/m^3)	2nd Maximum 24-hour PM_{10} concentration* (µg/m^3)
Condition Icon Definition	**Condition Icon**		
Warrants significant concern	(red circle)	≥ 35.5	≥ 155
Warrants moderate concern	(yellow circle)	12.1 – 35.4	55 – 154
Resource in good condition	(green circle)	≤ 12.0	≤ 54

* Measured three-year average.

Measure of Particulate Matter: PM_{10} Concentration

The standard for PM_{10} is 150 µg/m^3 for 24-hours (not to be exceeded more than once per year over 3 years).

We evaluated available data over the most recent three years of the sampling period. For NPS units that are outside particulate matter nonattainment areas, EPA AQI breakpoints were used to assign a particulate matter condition based on 3-year average of 2nd maximum 24-hour PM_{10} concentrations (Table 4.4.5). NPS units that are in EPA designated nonattainment areas for particulate matter are assigned Warrants Significant Concern condition for particulate matter.

Indicator: Nitrogen Deposition

Airborne pollutants can be atmospherically deposited to ecosystems through rain and snow (wet deposition) or dust and gases (dry deposition). Nitrogen pollution can harm ecosystems by acidifying or enriching soils and surface waters.

The term "acid rain" includes all precipitation that transports acidifying compounds (primarily sulfuric and nitric acids) out of the atmosphere to the earth's surface. Fuel combustion, industrial processes, and volcanic eruptions produce S- and N-compounds (EPA 2011) that can alter terrestrial and aquatic ecosystems through both dry and wet deposition (Driscoll et al. 2001). Dry deposition occurs when dust or smoke incorporate S- and N-particles that then settle on the ground, whereas wet deposition occurs when particles combine with water droplets and fall as rain, snow, or other forms of precipitation (EPA 2011). The deposition of S- and N-compounds can acidify water and soil (Likens et al. 1996), potentially reducing biodiversity and increasing ecosystem susceptibility to eutrophication and invasive species (Bouwman et al. 2002). Wet deposition of nitrates has generally decreased in the U.S. during the last 20 years (Du et al. 2014), but total nitrogen deposition has increased in places (Figure 4.4.7; Kim et al. 2011).

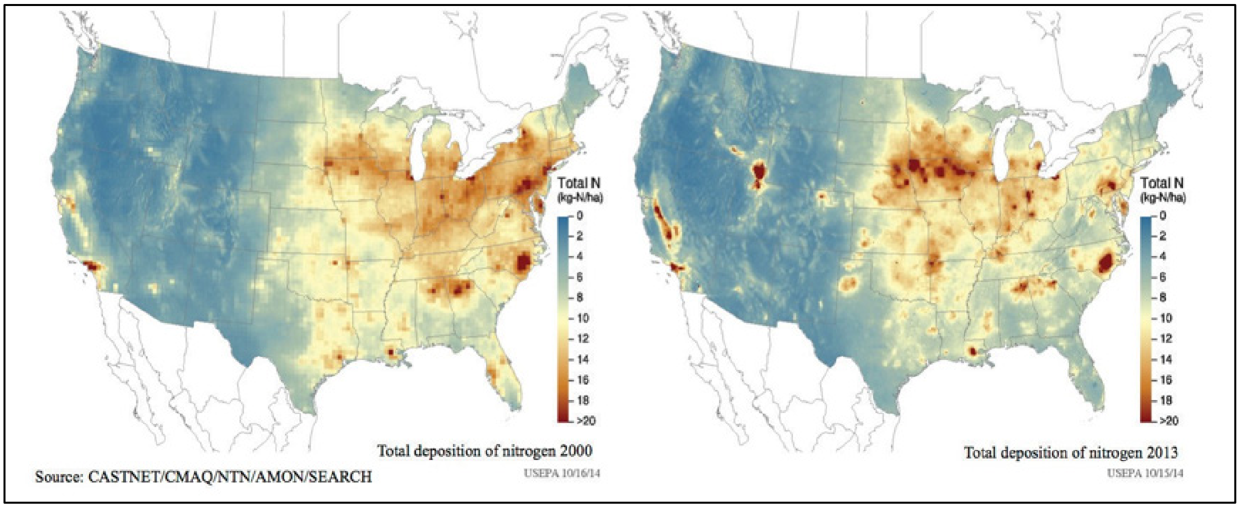


Figure 4.4.7. Total nitrogen deposition for the United States for 2000 and 2013. Total wet nitrogen deposition has decreased in some parts of the United States and increased in others. Maps from EPA 2014 http://castnet/cmaq/ntn/amon/search.

Nitrogen, a fertilizer, can disrupt the soil nutrient cycle and change plant communities where it is deposited. Plants in grassland ecosystems are particularly vulnerable to changes caused by nitrogen deposition, as they are often N-limited. In these grasslands, an influx of nitrogen enables exotic invasive grasses to displace native species that are adapted to a low nitrogen environment.

For example, increased deposition of nitrogen has allowed cheatgrass (*Bromus tectorum*), a highly invasive grass that has spread vigorously throughout the northern Great Plains (Ogle and Reiners 2002) the southern Colorado Plateau, Great Basin, and Mojave Desert, weedy annual grasses (e.g., cheatgrass), to outpace and replace native species (Brooks 2003; Schwinning et al. 2005; Chambers et al. 2007; Mazzola et al. 2008; Vasquez et al. 2008; Allen et al. 2009). Water use can change with nitrogen increases, such that plants like big sagebrush have reduced water use efficiency (Inouye 2006).

Measure of Nitrogen Deposition: Wet Deposition of N (kg/ha/yr)

Wet deposition is the most common and simplest way to measure deposition of nitrogen. Dry deposition data for nitrogen is difficult to obtain because dry deposition is not measured directly (Mickler et al. 2000, Freedman 2013). Wet deposition of nitrogen is measured in kilograms per hectare per year (kg/ha/year).

Nitrogen wet deposition is monitored across the United States as part of the National Atmospheric Deposition Program/National Trends Network (NADP/NTN). Annual wet deposition is averaged over a 5-year period at monitoring sites with at least 3 years of annual data and interpolated for the contiguous U.S. For individual parks, minimum and maximum values within park boundaries are reported from this national analysis. To maintain the highest level of protection in the park, the maximum value is assigned a condition status.

To assign a condition for nitrogen, we used the wet deposition results from the NPS-ARD report on condition and trends (NPS-ARD 2015b) from 2009–2013. Total wet deposition of nitrogen levels were calculated from interpolated data (NPS-ARD 2015b), using monitoring sites that were not on site at Agate Fossil Beds NM.

While ecosystems respond to total (wet and dry) deposition, NPS-ARD selected a wet deposition threshold of 1.0 kg/ha/yr as the level below which natural ecosystems are likely protected from harm. A resulting condition greater than 3 kg/ha/yr is assigned a *Warrants Significant Concern* status (Table 4.4.6). A current nitrogen condition from 1–3 kg/ha/yr is assigned *Warrants Moderate Concern status*. *Resource in Good Condition* was assigned if the current nitrogen condition is less than less than 1 kg/ha/yr.

Table 4.4.6. Air quality condition categories for wet deposition (NPS-ARD 2015a).

Resource condition		Wet deposition* (kg/ha/yr)
Condition Icon Definition	**Condition Icon**	
Warrants significant concern		> 3
Warrants moderate concern		1 – 3
Resource in good condition		< 1

* Estimated or measured 5-year average of nitrogen or sulfur wet deposition.

Condition Adjustments: Nitrogen Deposition

If Agate Fossil Beds NM was at very high risk for nutrient enrichment effects from atmospheric deposition relative to all Inventory & Monitoring parks, the condition for nitrogen deposition was adjusted to the next worse category.

To assess park risk of eutrophication we used a risk assessment conducted by Sullivan et al. (2011a) that combined measures of pollutant exposure, ecosystem sensitivity and park protection to calculate a summary risk. If the park was assigned an ecosystem sensitivity risk of Very High for nutrient enrichment, we moved the condition for nitrogen deposition to the next worse category.

Indicator: Mercury Deposition

Mercury and other toxic pollutants (e.g., pesticides, dioxins, PCBs) accumulate in the food chain and can affect both wildlife and human health. These pollutants enter the atmosphere from contaminated soils, industrial practices, and air pollution (Selin 2009). High levels of mercury and other airborne toxins can accumulate in fat and muscle tissues in animals, increasing in concentration and they move up the food chain. As neurotoxins, these pollutants can cause serious damage to ecosystems and their inhabitants and reduce survival of diverse species from fish to mammals.

While some sources of atmospheric mercury are natural, such as geothermal vents and volcanoes, most sources are anthropogenic; these sources include commercial incineration, mining activities, and coal combustion. These human include by-products of coal-fire combustion, municipal and medical incineration, mining operations, volcanoes, and geothermal vents (NPS-ARD 2015b).

A major contributor of mercury to inland areas is atmospheric deposition. Wet and dry deposition can lead to mercury loadings in surface waters, where mercury may be converted to a bioavailable toxic form of mercury, methylmercury, and bioaccumulate through the food chain.

Measure of Mercury Deposition: Wet Deposition of Hg (μg/m^2/yr) and Methylmercury Risk (ng/L)

Mercury deposition condition was assessed using estimated 3-year average mercury wet deposition (micrograms per meter squared per year [μg/m^2/yr]) and predicted surface water methylmercury concentrations (nanograms per liter [ng/L]). It is important to consider both mercury deposition inputs and ecosystem susceptibility to mercury methylation when assessing mercury condition because atmospheric inputs of elemental or inorganic mercury must be methylated before they become biologically available and able to accumulate in food webs (NPS-ARD 2015a). Thus, mercury condition cannot be assessed according to mercury wet deposition alone. Other factors like environmental conditions conducive to mercury methylation (e.g., dissolved organic carbon, pH) must also be considered (NPS-ARD 2015a).

Annual mercury wet deposition measurements are averaged over a 3-year period at all NADP-MDN monitoring sites with at least 3 years of annual data. Three-year averages are then interpolated across all monitoring locations using an inverse distance weighting method for the contiguous U.S. For individual parks, minimum and maximum values within park boundaries are reported from this national analysis. The maximum value is assigned a rating (Table 4.4.7).

Table 4.4.7. Ratings for mercury deposition (NPS-ARD 2015a).

Rating	Mercury deposition (μg/m^2/yr)
Very high	≥ 12
High	≥ 9 and < 12
Moderate	≥ 6 and < 9
Low	≥ 3 and < 6
Very low	< 3

Conditions of predicted methylmercury concentration in surface water are obtained from a model that predicts surface water methylmercury concentrations for hydrologic units throughout the U.S. based on relevant water quality characteristics (i.e., pH, sulfate, and total organic carbon) and wetland abundance (USGS 2015). The predicted methylmercury concentration at a park is the highest value derived from the hydrologic units that intersect the park. This highest value is then assigned a rating from very low to very high (Table 4.4.8).

Table 4.4.8. Ratings for predicted methylmercury concentration (NPS-ARD 2015a).

Rating	Predicted methylmercury concentration (ng/L)
Very high	≥ 0.12
High	≥ 0.075 and < 0.12
Moderate	≥ 0.053 and < 0.075
Low	≥ 0.038 and < 0.053
Very low	< 0.038

Ratings for mercury wet deposition and predicted methylmercury concentration are then considered concurrently in the mercury status assessment matrix (Table 4.4.9) to identify one of three park-specific mercury/toxics status categories: *Resource in Good Condition*, *Warrants Significant Concern*, or *Warrants Significant Concern*.

Table 4.4.9. Mercury condition assessment matrix (NPS-ARD 2015a).

Predicted methylmercury concentration rating*	Mercury wet deposition rating				
	Very low	Low	Moderate	High	Very high
Very low	Good	Good	Good	Moderate	Moderate
Low	Good	Good	Moderate	Moderate	Moderate
Moderate	Good	Moderate	Moderate	Moderate	Significant concern
High	Moderate	Moderate	Moderate	Significant concern	Significant concern
Very high	Moderate	Moderate	Significant concern	Significant concern	Significant concern

Condition Adjustments

The presence of in-park data on either mercury or toxins in food webs may influence the overall rating for mercury condition. An assessment of previous and current studies and availability of fish consumption guidelines serve as the basis for adjusting mercury status. There were no park-specific studies examining contaminant levels that were appropriate for condition adjustment.

Quantifying Air Quality Condition, Confidence, and Trend

To quantify air quality condition and trend, we deferred to the NPS-ARD methods for air quality assessment and used a point system to assign the indicator to a category (NPS-ARD 2015a). This points system is based on the NPS-ARD methods for calculating overall air quality condition: measures that placed the indicator in the *Warrants Significant Concern* category were assigned zero points, *Warrants Moderate Concern* measures were given 50 points, and *Resource in Good Condition* measures were given 100 points. If different measures each placed the indicator in a different condition category, as could be the case for ozone, then the measure with the worst category determined the condition for the indicator (NPS-ARD 2013). We then used the average of these points to assign the indicator to an overall category.

Indicator Confidence

Confidence ratings were based on the type of pollutant, distance to monitor used for interpolated data, time since data collection, and data robustness. We gave a rating of *High* confidence when monitors were on site or nearby, data were collected recently, and the data were collected methodically. We assigned a *Medium* confidence rating when monitors were not nearby, data were not collected recently, or data collection was not repeatable or methodical. We assigned *Low* confidence ratings when there were no good data sources.

Indicator Trend

Potential trend categories were *Improving*, *Unchanging*, or *Deteriorating*. To calculate a trend, we required data that were collected "over a 10-year period at on-site or nearby monitors (within 10 kilometers of the park for ozone, 16 kilometers of the park for wet deposition, and 100 kilometers of the park for visibility)" (NPS-ARD 2013, NPS-ARD 2015a). If there were no data available that met these distance and monitoring durations for a particular indicator, we indicated that trend was *Not Available* for that indicator.

Overall Air Quality Condition, Trend, and Confidence

To assess overall air quality condition, we used the NPS-ARD method to assign points to each indicator based on condition (NPS-ARD 2015a). We assigned zero points to indicators in *Warrants Significant Concern* category, 50 points to indicators in the *Warrants Moderate Concern* category, and 100 points to indicators in the *Resource in Good Condition* category. The average of the points for each measure was the total score for air quality condition (Table 4.4.10); high scores (67–100) indicated that air quality was in *Good Condition*, medium scores (34–66) indicated that it *Warrants Moderate Concern*, and low scores (0–33) indicated that air quality condition *Warrants Significant Concern*. We applied the EPA non-attainment status adjustments to the overall condition, such that if the NPS unit fell in an area that was in "nonattainment" for ozone or particulate matter, the overall condition would be *Warrants Significant Concern* (NPS-ARD 2015a).

If trend data were available, we calculated overall air quality trends using a points system to assign an overall trend category of *Improving*, *Unchanging*, or *Deteriorating*. Specifically, we subtracted the number of deteriorating trends from improving trends. If the result of this calculation was > 3, the overall trend was *Improving*. If the result was < −3, the overall trend was *Deteriorating*. If the result was between > −2 and < 2, the overall trend was *Unchanging*. If any indicator did not have a trend, then there was no trend for overall condition (NPS-ARD 2015a).

Overall confidence categories were *High*, *Medium*, or *Low* (NPS-ARD 2013). We calculated confidence using a points system similar to overall condition confidence; categories with *High* confidence received 100 points, *Medium* confidence received 50 points, and *Low* confidence received zero points. The overall confidence was *High* if the average of these values was between 67 and 100, *Medium* between 34 and 66, and *Low* between 0 and 33.

Table 4.4.10. Overall air quality condition categories.

Resource condition		Score
Condition Icon Definition	**Condition Icon**	
Warrants significant concern		0 – 33
Warrants moderate concern		34 – 66
Resource in good condition		67 – 100

4.4.4. Air Quality Conditions, Confidence, and Trends

<u>Visibility</u>

Condition: Warrants Moderate Concern
Confidence: High
Trend: Improving

Condition

The Haze Index for 2009–2013 was 4.9 dv, which placed visibility for Agate Fossil Beds National Monument in the *Warrants Moderate Concern* category.

Confidence

The closest IMPROVE monitoring site was at Wind Cave National Park; this location was close enough to Agate Fossil Beds NM for NPS-ARD to assign *High* a level of confidence to visibility (NPS-ARD 2015b).

Trend

Visibility data were collected for at least 10 years at a location close to Agate Fossil Beds NM, which meant that a trend calculation could be completed. The visibility trend at Agate Fossil Beds NM was *Improving*.

<u>Ozone</u>

Condition: Warrants Moderate Concern
Confidence: Medium
Trend: Not Available

Condition

Human health condition: The calculated ground-level ozone concentration from 2009–2013 was 64.7 ppb, which placed ozone pollution at Agate Fossil Beds NM in the *Warrants Moderate Concern* category.

Vegetation health condition: The W126 value for Agate Fossil Beds NM was 9.8 ppm-hrs, which placed the vegetation health risk in the *Warrants Moderate Concern* category. A study of ozone risk to plants concluded that risk of damage was *Low* at Agate Fossil Beds NM (Kohut 2004). Ozone-sensitive plants were present (Table 4.4.11) and one threshold for injury to plants was exceeded; if risk increased an assessment of damage to plants would be warranted (Kohut 2004). The *Low* rating for risk of foliar damage meant the condition for ozone pollution remained in the *Warrants Moderate Concern* category.

Table 4.4.11. Ozone-sensitive plants at Agate Fossil Beds NM.

Family	Species name	Common name
Rosaceae	*Amelanchier alnifolia*	Saskatoon serviceberry
Apocynaceae	*Apocynum androsaemifolium*	Spreading dogbane
Oleaceae	*Fraxinus pennsylvanica*	Green ash
Pinaceae	*Pinus ponderosa*	Ponderosa pine
Salicaceae	*Populus tremuloides*	Quaking aspen
Anacardiaceae	*Rhus trilobata*	Skunkbush
Caprifoliaceae	*Symphoricarpos albus*	Common snowberry

Confidence

Ozone levels were calculated from interpolated data collected at distant a monitoring stations, so the confidence was *Medium* (NPS-ARD 2015b).

Trend

There were insufficient data nearby or on-site at Agate Fossil Beds NM, so a trend for ozone was *Not Available*.

Particulate Matter

Condition: Resource in Good Condition
Confidence: Medium
Trend: Not Available

Condition

Agate Fossil Beds NM is located in Sioux County, Nebraska, that met the 2012 and 2006 $PM_{2.5}$ standards and 1987 PM_{10} standard. For this reason, the county is an EPA-designated "attainment" area for particulate matter.

The measured 3-year average (2013–2015) of the 98th percentile 24-hour $PM_{2.5}$ concentration for Sioux County was 6.2 $\mu g/m^3$, which falls in the *Resource in Good Condition* category (EPA 2016c). PM_{10} concentration was 19.4 Rawlinson g/m^3 for 2011–2013, which mean that the *Resource in Good Condition*. The overall particulate matter condition falls into the *Resource in Good Condition category*.

Confidence

The particulate matter condition was calculated from monitors not located with Agate Fossil Beds, so the confidence was *Medium*.

Trend

Trend was *Not Available*.

Nitrogen Deposition

Condition: Warrants Significant Concern
Confidence: Medium
Trend: Not Available

Condition

The total N wet deposition level from 2009–2013 was 1.9 kg/ha, which placed total N wet deposition pollution at Agate Fossil Beds NM in the *Warrants Moderate Concern* category. The Sullivan et al. (2011a, 2011b) studies assessing ecosystem risks from N and S wet deposition assigned overall summary risks to Agate Fossil Beds NM for susceptibility to acidification and eutrophication. Agate Fossil Beds NM was at Moderate risk for acidification from N deposition (Sullivan et al. 2011b) and Moderate risk for nutrient enrichment from N deposition (Sullivan et al. 2011a), but was ranked high for sensitivity to acidification relative to other Inventory and Monitoring parks (NPS-ARD 2015b).

Because of this High ranking relative to other parks, Nitrogen at Agate Fossil Beds NM was placed it the *Warrants Significant Concern* category (NPS-ARD 2015b).

Confidence

None of the monitoring stations for wet deposition were on site in Agate Fossil Beds NM or within 16 kilometers (NPS-ARD 2013, NPS-ARD 2015a), so the confidence was *Medium*.

Trend

The closest monitoring site for wet deposition was a National Atmospheric Deposition Program (NADP 2014) site approximately 129 kilometers away at Wind Cave National Park. The maximum distance allowed for calculating a trend in wet N deposition is 16 kilometers away from a park unit, so we could not calculate trend (NPS-ARD 2013a). Trend was *Not Available*.

<u>Sulfur Deposition</u>

Condition: Resource in Good Condition
Confidence: Medium
Trend: Not Available

Condition

The total S wet deposition level from 2009–2013 was 0.6 kg/ha, which placed total S wet deposition pollution at Agate Fossil Beds NM in the *Resource in Good Condition* category.

Sullivan et al. (2011b) assessed overall susceptibility to acidification from S wet deposition based on a combination of pollutant exposure, ecosystem sensitivity, and park protection. Agate Fossil Beds NM was at Low risk for acidification from S deposition (Sullivan et al. 2011b). Sulfur wet deposition at Agate Fossil Beds NM remained in the *Resource in Good Condition* category (NPS-ARD 2015b).

Confidence

None of the monitoring stations for wet deposition were on site or within 16 kilometers (NPS-ARD 2013, NPS-ARD 2015b), so the confidence was *Medium*.

Trend

The closest monitoring site for wet deposition was a National Atmospheric Deposition Program (NADP) site approximately 129 kilometers away at Wind Cave National Park. The maximum distance allowed for calculating a trend in wet S deposition is 16 kilometers away from a park unit and must include 10 years of data, so we could not calculate trend (NPS-ARD 2013a). Trend was *Not Available*.

<u>Mercury Deposition</u>

Condition: Not Available
Confidence: Low
Trend: Not Available

Condition

Given that landscape factors influence the uptake of mercury in the ecosystem, the condition is based on estimated wet mercury deposition and predicted levels of methylmercury in surface waters. The 2011– 2013 estimated wet mercury deposition is low at the park, ranging from 5.4 to 5.5 µg/m^2/yr (K. Taylor, personal communication, 26 May 2016). We could not calculate a condition for this park cannot be because we only had wet deposition data. In order to have a condition, a park needs to have both wet deposition and methylmercury data. Condition was *Not Available*.

Confidence

The degree of confidence in the mercury/toxics deposition condition is low because there are no park-specific studies examining contaminant levels.

Trend

Trend was *Not Available*.

Air Quality Overall Condition

The overall air quality condition was determined by the average of the indicator conditions (Table 4.4.12. We summarized the condition, confidence, and trend for each indicator (Table 4.4.13), and assigned condition points as specified by NPS-ARD (NPS-ARD 2015a). The total score for overall air quality condition was 50 points, which placed Agate Fossil Beds NM in the *Warrants Moderate Concern* category.

Table 4.4.12. Air quality overall condition.

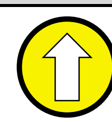
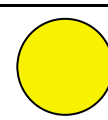
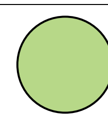
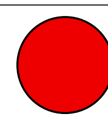
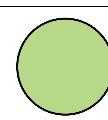
Indicators	Measures	Condition
Visibility	• Haze index (dv)	
Ozone	• Human health (ppm) • Vegetation health (W126 index)	
Particulate matter	• $PM_{2.5}$ (ppm) • PM_{10} (ppm)	
Nitrogen	• Wet deposition (kg/ha/year)	
Sulfur	• Wet deposition (kg/ha/year)	

Table 4.4.12 (continued). Air quality overall condition.

Indicators	Measures	Condition
Mercury	• Wet deposition (µg/m²/year) • Methylmercury risk	
Overall condition for all indicators and measures		

Table 4.4.13. Summary of air quality indicators and measures.

Indicator	Measure	Condition	Confidence	Trend	Condition rationale
Visibility	Haze index (dv)	Warrants moderate concern	High	Not available	Visibility from 2009–2013 was 4.9 dv; this value placed visibility in the *Warrants Moderate Concern* category. Data came from nearby monitoring location at WICA, so confidence was *High* and trend was *Improving*.
Ozone	Human health (ozone concentration)	Resource in good condition	Medium	Not available	Ozone from 2009–2013 was 64.7 ppb; this value placed ozone in the *Warrants Moderate Concern* category. Data were interpolated from monitors not within the necessary radius to calculate a trend; confidence was *Medium* and trend was *Not Available*.
	Vegetation health (W126 measure)	Warrants moderate concern	Medium	Not available	The biologically relevant W126 value was 9.8 ppm-hrs, which placed vegetation health condition in the *Warrants Moderate Concern* category. Risk of foliar damage was *Low*.
Particulate matter	$PM_{2.5}$	Warrants moderate concern	Medium	Not available	$PM_{2.5}$ for 2013–2015 was 6.2 µg/m³; this valued placed $PM_{2.5}$ in the *Resource in Good Condition* category. There were no data collected on site or nearby, so confidence was *Medium* and trend was *Not Available.*
	PM_{10}	Resource in good condition	Medium	Not available	PM_{10} for 2013–2015 was 19.4 µg/m³; this valued placed PM_{10} in the *Resource in Good Condition* category. There were no data collected on site or nearby, so confidence was *Medium* and trend was *Not Available.*

Table 4.4.13 (continued). Summary of air quality indicators and measures.

Indicator	Measure	Condition	Confidence	Trend	Condition rationale
Nitrogen deposition	Wet deposition (kg/ha/yr)	Warrants significant concern	Medium	Not available	Total wet deposition of N from 2009–2013 was 1.9 kg/ha/yr. This value placed total N wet deposition pollution in the *Warrants Moderate Concern* category, but the risk of acidification was high relative to other parks, so the category was adjusted to *Warrants Significant Concern.* There were no data collected on site or nearby, so confidence was *Medium* and trend was *Not Available*.
Sulfur deposition	Wet deposition (kg/ha/yr)	Resource in good condition	Medium	Not available	Total average wet deposition level from 2009– 2013 was 0.6 kg/ha S; total S wet deposition was in the Resource in Good Condition category. Risk of acidification was Moderate, so the category did not need to be adjusted. There were no monitoring data available from on site or nearby; confidence was Medium and trend was Not Available.
Mercury deposition	Wet deposition (µg/m2/yr) and methylmercury rating	Not available	Low	Not available	Methylmercury rating was not available so condition was Not Available.

Confidence

Confidence was *High* for Visibility, *Low* for mercury, and *Medium* for all other indicators. The score for overall confidence was 50 points, which met the criteria for *Medium* confidence in overall air quality.

Trend

Trend data were *Not Available* for all but one indicator, so overall trend for air quality was *Not Available.*

4.4.5. Stressors

Potential air quality stressors include Western Sugar Cooperative plants 55 kilometers southwest in Torrington, WY, and 63 kilometers to the south in Scottsbluff, NE, the Basin Electric Laramie River Station, a coal-fired power plant 100 kilometers southwest of Agate Fossil Beds NM (US EIA 2015), smoke from fires during the summer months, and oil and gas drills to the south and west.

Agate Fossil Beds NM is located just outside of three major oil and gas basins. The Powder River Basin (PRB) is the closest, located to the west and northwest of the Agate Fossil Beds NM in eastern Wyoming, southwestern South Dakota, and southeastern Montana. The Denver-Julesburg is located to the south of Agate Fossil Beds NM in north eastern Colorado, and the Williston Basin is located to the north of Agate Fossil Beds NM in western North Dakota. Each of these basins contains extensive existing oil and gas development. The PRB, the closest basin to the park, has seen extensive oil, gas, and coalbed methane development, as well as extensive surface coal mining. According to data from the Wyoming oil and gas conservation commission, the Powder River Basin contained approximately 40,775 well sites as of 2015, with just over half of these sites in some type of active status (http://wogcc.state.wy.us). Equipment associated with oil and gas development and production, such as drill rigs, fracturing engines, valves, seals, and compressors, emit air pollutants (nitrogen oxides, greenhouse gases, particulate matter, and hydrogen sulfide), and in regions of extensive development, can cause air quality concerns. Air quality modeling indicates that currently oil and gas development to the west may be affecting park air quality to some extent, including potential ozone effects to vegetation (K. Taylor, personal communication, 26 May 2016).

4.4.6. Data Gaps

Most of the available air quality data for Agate Fossil Beds NM were interpolated from monitors not within the park boundaries, with the exception of the visibility data. The lack of monitoring data at the park unit or nearby limited the level of confidence at which we could assign indicator conditions and overall air quality condition. Additionally, it is preferable not to calculate air quality trends from interpolated data (NPS-ARD 2015a), so it is unclear how conditions other than visibility may have changed at Agate Fossil Beds NM over time.

Acknowledgments

- Ksienya Taylor (NPS)

4.4.7. Literature Cited

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4.5. Water Quality

4.5.1. Background and Importance

Surface waters form complex ecosystems that support a vast number of uses. They provide critical wildlife and plant habitat, sources and sinks in water and nutrient cycles, and numerous recreational opportunities. Surface waters are also aesthetic resources and, often, public health resources when they connect to a drinking water supply. The water quality of streams, rivers, wetlands, ponds, lakes, springs, and other water bodies determines their suitability for these various uses (Boyd 2015). Indicative of the importance of water in park units, NPS identified water quality as a core natural resource (NPS 2009) to include in its nationwide ecosystem monitoring program (Fancy and Bennetts 2012).

The Niobrara River flowing through Agate Fossil Beds NM. The water quality in the river has been compromised by the spread of non-native yellow iris (Photo by Rod Stolcpart, 2014).

The Clean Water Act (33 USC § 1251 et seq 1972) provides a general structure for surface water quality regulation in the U.S. and the National Park Service places a high priority on improving and protecting water quality in park units (NPS 1999). The National Park Service is dedicated to protecting water quality as a top resource within the Northern Great Plains Network (NGPN) (Wilson et al. 2014). Surface waters are affected by environmental conditions within and beyond their banks, so effective water quality management strategies have an equally broad focus. Public lands and waters under the jurisdiction of NPS are in the unique position of receiving regulatory and managerial priority for water quality protection, which facilitates the protection of surface waters as well as groundwater (NPS 2006a).

<u>Regional Context</u>

Most rivers and tributaries in the NGPN feed the Missouri River, which flows into the Mississippi River (Figure 4.5.1). The Missouri River is the longest river in the U.S. (Kammerer 1990) and drains 1.3 million kilometer^2 of upstream land (Seaber et al. 1987). This drainage basin continues to be affected by the construction of dams, levees, reservoirs, and canals for agricultural, industrial, and infrastructural activities since the 19th century (Buie 1980, Brown et al. 2011).

Agate Fossil Beds NM is located in northwest Nebraska on the Niobrara River in the Niobrara River Drainage (Middle North Platte-Scotts Bluff Watershed), which eventually flows east into the Missouri River. The Niobrara River is a prominent natural feature that bisects the park unit and is an important resource for agriculture (NE DNR 2015), recreation (NE Game and Parks 2015), and plants and wildlife in the region. Downstream of Agate Fossil Beds NM, the largely undisturbed Niobrara River is a designated National Scenic River for its unique natural and cultural resources (NPS 2006b). Protecting water quality in the Niobrara River at Agate Fossil Beds NM is a high regional priority for NPS (Wilson et al. 2014).

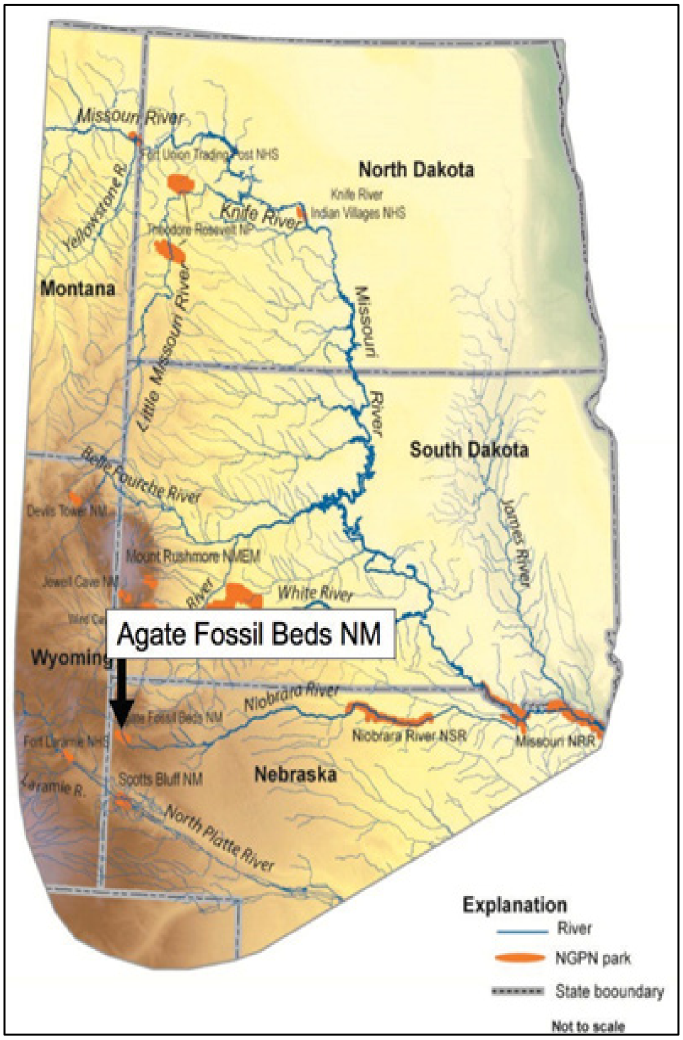


Figure 4.5.1. Tributaries and rivers in NGPN park units (Wilson et al. 2014).

4.5.2. Water Quality Standards

States and tribes must protect or enhance water quality in accordance with the Clean Water Act. State law and tribal codes therefore specify designated uses for every water body or stream segment; uses may include water supply, aquatic life, recreation, aesthetics, and navigation. These designated uses are water quality goals, management objectives, and activities that the water body supports. Water bodies are held to regulatory criteria for these designated uses, regardless of whether or not those standards are currently attained (EPA 2014) or if the water bodies are impaired and, therefore, subject to 303d listing.

The U.S. Environmental Protection Agency (EPA) publishes water quality criteria to guide standards set by states and tribes. States adopt or modify the criteria to create more stringent standards, which must then be approved by EPA (40 CFR §131.5 1998). States set water quality standards at two levels: for human use and use by aquatic life. For each of these levels, standards are calculated for acute and chronic exposure such that pollutants are not expected to pose a significant risk for the designated use.

The NGPN has worked with the U.S. Geological Survey (USGS) to identify water resource priorities and key indicators of water quality within the entire network and within each network park. The section of the Niobrara River that runs along Agate Fossil Beds NM is a relatively low priority for NGPN compared to other rivers and tributaries in the NPS network (Wilson et al. 2014), but is designated for recreation, aesthetics, aquatic life, and water supply of agriculture by the state and regulated for those uses (117 Nebraska Administrative Code § 81.1501 2014).

The Niobrara River in Agate Fossil Beds NM is a Class B Coldwater stream managed for aquatic life, which means that it does not support naturally reproducing salmonid populations, but supports other coldwater organisms, including various fish, and may support seasonal salmonid migrations. The water supply designation of Class A for Agriculture allows for general agricultural use without treatment (117 Nebraska Administrative Code § 81.1501 2014). The aquatic life use water quality standards, which were used for this assessment, are stricter than agricultural water supply standards.

Some water quality standards vary with season and aquatic life stages, particularly to protect spawning stages of fish species. In Nebraska, water quality standards depend on the stream classification, and surface waters with a Class B Coldwater designation, like the North Platte, are regulated to the following water quality standards for pH, dissolved oxygen (Table 4.5.1), temperature, conductivity, and E. coli (J. Bender, personal communication, 2 December 2015; 117 Nebraska Administrative Code § 81.1501 2014):

- **pH:** 6.5–9.0
- **Temperature**: ≤ 22°C and, within mixing zones, less than a three-degree difference from the natural background temperature outside of mixing zone.
- **Conductivity:** ≤ 2,000 Siemens/meter from April 1–September 30.
- **Turbidity:** The criteria for turbidity are entirely descriptive and placed in the context of aesthetics. All waters must be free from non-natural sources of pollution that cause cloudiness or haziness.
- ***Escherichia coli* (*E. coli*):** 30-day geometric mean concentration < 126 colony forming units/100 milliliters.
- **Streamflow:** Water quality standards apply to all waters outside of acute mixing zones (limited areas encompassing point-source discharge) and above a critical low streamflow (117 Nebraska

Administrative Code § 81.1501 2014). Streamflow is the amount of water that flows in a river or stream, eventually reaching the ocean.

Table 4.5.1. Dissolved oxygen (DO) criteria by date.

Value calculation	Dates when criterion applies*	Criterion value (mg/L)
One day minimum	April 1–June 30	≥ 5.0
One day minimum	July 1–March 31	≥ 4.0
Seven day mean	April 1–June 30	≥ 6.5
Seven day mean minimum	July 1–March 31	≥ 5.0
30 day mean	July 1–March 31	≥ 6.5

* Seasonal variation protects early life stages of coldwater fish.

Flow changes seasonally with precipitation events, but land use changes can also affect streamflow. Diversions for agriculture, flow regulation for reservoir or hydropower management (Botter et al. 2010), and surface changes that affect runoff (Herb et al. 2008) can alter the total amount of water flowing in a river and affect water quality indicators. While the organisms that inhabit rivers have evolved in seasonally variable streamflow conditions, anthropogenic changes in streamflow can have ecological consequences for aquatic communities (e.g., Poff and Zimmerman 2010).

The flow regime in every river is different, so each river should be compared to itself over time and considered in a regional context. If trends in low and high flows in a river are inconsistent with regional trends, that pattern could indicate a change in land or river use. For trends that are consistent with regional condition, flow rate changes may indicate broader environmental change. There are no set parameters for evaluating the flow status of an individual stream, but there are flow rate limits at which certain water quality values are not valid.

For Coldwater Class B streams in Nebraska, such as the Niobrara River, narrative criteria, general criteria, and acute toxicity water quality standards apply to waters flowing above 0.1 cubic feet per second (ft^3/s), while criteria for chronic exposure (> 96 hrs) do not apply below this critical low flow (117 Nebraska Administrative Code § 81.1501 2014); all standards apply above this flow rate.

4.5.3. Methods

Overall water quality condition depends on the individual conditions of multiple indicators (Figure 4.5.2). The water quality indicators that we considered for this assessment were either regulated by the Nebraska Department of Environmental Quality (117 Nebraska Administrative Code § 81.1501 2014) or identified as key indicators by NPS (Wilson et al. 2014). NPS requires that each network monitor core parameters (DO, pH, specific conductivity, water temperature) for surface waters within park boundaries. Collecting data for these core parameters is relatively straightforward and can give a general description of water quality, but including other water quality indicators gives a more robust assessment of overall health of the aquatic environment. The NGPN protocol for surface water monitoring incorporates an additional suite of advanced water quality indicators, including aquatic microorganisms (primarily *E. coli* bacteria) and aquatic macroinvertebrates (Wilson et al. 2014).

These biological indicators reflect different aspects of water quality and can affect human and environmental health in different ways. Therefore, we considered these biological parameters in our assessment alongside the core parameters and turbidity, a physical aspect of surface water. We considered all indicators and measurements in the context of streamflow, as flow rates determine the applicability of water quality standards.

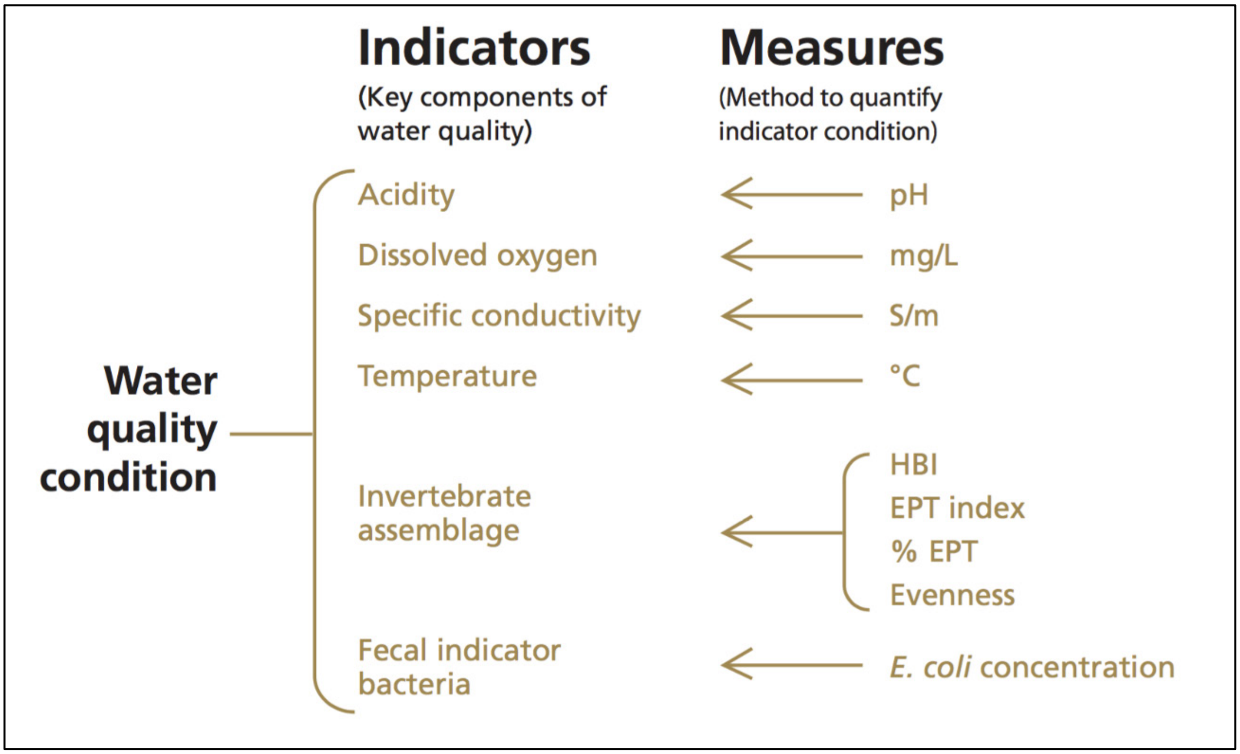


Figure 4.5.2. Schematic of the factors considered in water quality condition assessment.

As of 2014 no park unit within NGPN had sufficient data for a comprehensive surface water quality assessment (Wilson et al. 2014). We have, however, used all available existing data to make as comprehensive an assessment as possible for water quality within Agate Fossil Beds NM and focused the most recent data available for each indicator. To assign a condition to each water quality indicator, we used measurements specified by Nebraska Department of Environmental Quality (117 Nebraska Administrative Code § 81.1501 2014), EPA, and expert opinion for indicators not regulated federally or by Nebraska DEQ. We assigned to each indicator one of three condition categories based on NPS water quality monitoring protocol (Wilson and Wilson 2014).

Water quality condition categories were *Resource in Good Condition*, *Warrants Moderate Concern*, and *Warrants Significant Concern* (Table 4.5.2); condition category was determined by the proportion of samples that were outside the range of allowed values. Ideally, samples would have been collected consistently over time at set monitoring locations, but when long-term data were unavailable, we used multiple samples collected over the length of a water body to assess condition in lieu of time. This approach allowed us to assign a category based on the proportion of those samples that exceeded Nebraska standards for water quality. We then considered all indicator conditions together in an overall water quality condition assessment. For indicators that did not have set standards, we relied on expert opinion and, where possible, adapted the NPS approach to assign a condition.

Table 4.5.2. Water quality condition categories for core parameters (acidity, dissolved oxygen, specific conductance, and temperature), which are determined by the percentage of observations that exceeded state standards (Wilson et al. 2014).

Resource condition		
Condition Icon Definition	**Condition Icon**	**% Exceedance**
Warrants significant concern		> 25%
Warrants moderate concern		5 – 25%
Resource in good condition		0 – 5%

* Percentage of samples above or below their respective state regulatory threshold.

Core Indicators and Measures

Indicator: Acidity

Most streams are naturally neutral; they are neither very acidic nor alkaline. The organisms that have evolved in these ecosystems are, therefore, adapted to relatively neutral water and many cannot survive in water that is either very acidic or alkaline (Figure 4.5.3). North American streams have become more acidic in the past 100 years from atmospheric deposition of sulfur and nitrogen, and this acidification has had a negative effect on stream ecosystems (Gleick et al. 1993). Some fish and macroinvertebrates are particularly sensitive to changes in pH and have declined in or have been extirpated from low pH streams (e.g., Mulholland et al. 1992, Baldigo and Lawrence 2001).

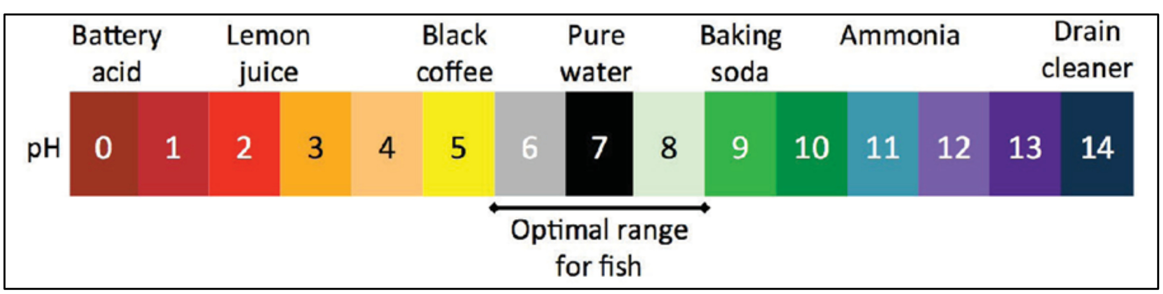


Figure 4.5.3. pH scale. Low and high pH waters are limiting for aquatic life; fish survive best at pH of 5–9.

Measure of Acidity: pH

The pH of a water sample measures the relative amount of free hydrogen ions (H+) and free hydroxyl ions (OH-) in the sample. Acidic water has more H+ and alkaline water has more OH-. The pH indicates the acidity of water on a logarithmic scale of 0 (most acidic) to 14 (most alkaline), where 7.0 is neutral. Standards for pH apply at all streamflow rates.

Indicator: Dissolved Oxygen (DO)

Dissolved oxygen is a critical resource for aerobic aquatic life (Boyd 2015), and low oxygen levels can damage macroinvertebrates and fish (Table 4.5.3; e.g., Davis 1975, Caraco and Cole 2002). Most fish do best when oxygen concentration is within 50–100% saturation (~5–10 milligrams/liter for a stream at 15°C), and dissolved oxygen tends to be highest in cold waters that receive low nutrient inputs (Boyd 2015). Oxygen solubility decreases as temperature increases (USGS 2014, Boyd 2015), and excessive nutrient inputs allow the explosive growth of algae—algae blooms that can temporarily increase DO. When algae die, however, microbes use oxygen to decompose the organic material; at high algal levels the consequent depletion of oxygen during decay can suffocate other aquatic life (Campbell and Reece 2009). Standards for DO apply at all streamflow rates, though only the 1-day acute criteria are applicable below critical low flow rates.

Table 4.5.3. Dissolved oxygen level ranges and corresponding effects on macroinvertebrate and fish. Dissolved oxygen concentration affects fish survival and health (Boyd 2015).

Dissolved oxygen (mg/L)	Effects
0 – 0.3	Small fish survive short exposure
0.3 – 1.5	Lethal if exposure is prolonged for several hours
1.5 – 5.0	Fish survive, but growth will be slow and fish will be more susceptible to disease
5.0 – saturation	Desirable range
Above saturation	Possible gas bubble trauma if exposure prolonged

Measure of DO: Milligrams Oxygen per Liter Water (mg/L)

Dissolved oxygen is measured as a mass concentration (mass per unit volume)—typically as milligrams per liter (mg/L) water.

Indicator: Specific Conductivity

Specific conductance, or conductivity, is the ability of a solution to conduct electricity. Conductivity increases with the concentration of ions in the water, which come from dissolved salts. Conductivity increases with salt content of water such that pure water has a very low specific conductance and sea water has a high conductance (Miller et al. 1988). Specific conductance is conductivity adjusted for temperature, and is important ecologically because of its relationship to salinity. Aquatic organisms are adapted to a range of salinity and are likely to suffer adverse effects at salt concentrations that are either too high or too low (Boeuf and Payan 2001, Horrigan et al. 2005).

Measure of Specific Conductivity: Siemens per Meter (S/m) or Microsiemens (µS/cm)

Specific conductivity is calculated from the conductance between two electrodes over a set distance. The unit for conductance at 25 °C is a siemens (Miller et al. 1988).

Indicator: Temperature

Fish, macroinvertebrates, microorganisms, and aquatic plants are limited to specific ranges of temperature. Temperature affects the solubility of salts and dissolved oxygen concentration (Boyd 2015), chemical toxicity in fish (Cairns et al. 1975), and various biochemical processes such as metabolic rate in fish (Gillooly 2001). Temperature fluctuates seasonally, and varies with the size and depth of a water body, its physical structure, the clarity of the water (Paaijmans et al. 2008), and flow rates or circulation rates. Standards for temperature apply at all streamflow rates.

Measure of Temperature: Degrees (°C or °F)

Temperature is measured in degrees Celsius (°C) or degrees Fahrenheit (°F). We present temperatures in °C to stay consistent with regulatory guidelines. The conversion between Celsius and Fahrenheit is approximately 0 °F = −17.8 °C, and the conversion formula is: T (°C) = (T (°F) – 32)/1.8.

Physical Indicators and Measures

Indicator: Turbidity

Turbidity is the cloudiness or clarity of water; low turbidity waters are relatively clear, while waters with high turbidity are opaque. Light scatters when it hits fine particles in water, such as silt, clay, and organic particles, and high scatter causes opacity. Turbidity can affect plant growth, macroinvertebrate productivity, and fish communities (Lloyd 1987, Lloyd et al. 1987). Sources of particulate matter that causes turbidity can be natural, such as from soil erosion during flood events, or anthropogenically induced, such as from wastewater discharge from urban areas (Petit et al. 2013).

Measure of Turbidity: Descriptive Aesthetic Condition

Turbidity is measured in a variety of units, but the nephelometric turbidity unit (NTU) has been adopted by most state and federal regulatory situations. Turbidity is the amount of light reflected by particles in a water sample. Relatively high concentrations of suspended particles in turbid samples have high light reflection and, therefore, high NTU measurements. Nebraska does not specify an NTU standard value, but rather, gives an aesthetic guideline that waters must be free from non-natural sources of pollution that cause cloudiness or haziness. Similar to our approach with quantitative measures, we assigned the turbidity condition based on the proportion of turbidity observations within park boundaries that violated these standards.

Biological Indicators and Measures

Indicator: Invertebrate Assemblage

Aquatic macroinvertebrates are small organisms that live in the sediment or on rocks at the bottom of lakes, rivers, and streams. They are visible to the naked eye and spend at least part of their lives in water. The composition of aquatic invertebrate communities can indicate long-term water quality condition that may not be reflected in periodic or short-term chemical and physical samples. Aquatic invertebrates experience and respond to a variety of water conditions in their environment for the duration of their lives—spanning weeks to many years (e.g., Martıñez 1998, Tronstad 2015a)—thus providing a comprehensive picture of overall water quality. Some invertebrate taxa are more sensitive to changes in water quality than other taxa, so measuring the proportion of those taxa in a stream is one way to measure water quality, but differences in stream channel shape, depth, and substrate, and natural water conditions can also account for differences in invertebrate presence and abundance. Therefore, comparing several measures of invertebrate community is ideal.

Measure of Invertebrate Assemblage: Hilsenhoff Biotic Index (HBI)

Some aquatic invertebrates are more sensitive to environmental conditions than others. The Hilsenhoff Biotic Index (HBI) is an overall tolerance index for a community that combines the estimated tolerance of individual species with their local abundance (Hilsenhoff 1987, 1988). This biotic index is calculated from the total number of individuals (N) in a sample where n is the number of individuals of taxonomic group i and a is the tolerance of that group:

$$HBI = \frac{\sum n_i a_i}{N}$$

Tolerance to pollution ranges from 0 for highly sensitive species, to 10 for highly tolerant species (Hilsenhoff 1987). We assigned a condition value to the HBI based on the overall community tolerance (Hilsenhoff 1988). Values from 0–4.50 indicated *Good Condition*, values from 4.51–6.50 indicted that water quality *Warrants Moderate Concern*, and values from 6.51–10.00 indicted that water quality *Warrants Significant Concern* (Table 4.5.4).

Table 4.5.4. Water quality condition categories for Hilsenhoff Biotic Index (HBI) scores (Hilsenhoff 1988).

Resource condition		
Condition Icon Definition	**Condition Icon**	**HBI score**
Warrants significant concern	Red circle	6.51 – 10.00
Warrants moderate concern	Yellow circle	4.51 – 6.50
Resource in good condition	Green circle	0 – 4.50

Measure of Invertebrate Assemblage: EPT Index

Three orders of macroinvertebrates— Ephemeroptera, Plecoptera, and Trichoptera—are particularly sensitive to pollution and are unlikely to occur in polluted waters when more tolerant groups are present. The presence of very few EPT species in a sample can indicate poor water quality, though EPT indices must be compared to EPT criteria that are specific to the region where data were collected. An EPT index is simply the total number (richness) of distinct species within each of the EPT orders. For example, a sample that contained three species belonging to Ephemeroptera, three species in Plecoptera, and four Trichoptera would have an EPT index of 10. We assigned condition to this measure based on background data for EPT numbers in the ecoregion (25f—Scotts Bluff and

Wildcat Hills) that included Scotts Bluff NM (Bazata 2011, 2013) and adapted the condition categories to fit conservatively into the three condition scheme we used for our assessment.

We assigned the condition *Warrants Significant Concern* to values below the 25th percentile (of samples collected from a variety of streams sampled in the region [Bazata 2011]), *Warrants Moderate Concern* to values from the 25th to the 75th percentile of all streams, and *Good Condition* to values above the 75th percentile of streams (Table 4.5.5).

Table 4.5.5. Water quality condition categories for the Ephemeroptera, Plecoptera, and Trichoptera (EPT) index (adapted from Hargett 2011).

Resource condition		
Condition Icon Definition	**Condition Icon**	**EPT index**
Warrants significant concern	(red circle)	< 7
Warrants moderate concern	(yellow circle)	7 – 13
Resource in good condition	(green circle)	> 13

Measure of Invertebrate Assemblage: Proportion or Percentage of EPT Taxa

Though EPT index is a good general measurement of water quality, the proportion of EPT to non-EPT taxa can improve on this measure. Taxa that are tolerant to pollution and EPT are all likely to be present in high-quality water bodies, but the proportion of EPT to more tolerant taxa declines as water quality declines (e.g., Tronstad 2015a). Condition ranges were not available for proportion of EPT for Nebraska, so we referred to reference conditions assigned to the upstream region in southeast Wyoming (Hargett 2011) and assigned condition based on these ranges (Table 4.5.6).

Table 4.5.6. Water quality condition categories for proportion of Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa (Hargett 2011).

Resource condition		Proportion EPT taxa
Condition Icon Definition	**Condition Icon**	
Warrants significant concern		< 0.38
Warrants moderate concern		0.38 – 0.68
Resource in good condition		> 0.68

Measures of Invertebrate Assemblage: Taxa Evenness

Evenness is a diversity index that describes the similarity in number of members that belong to different groups in a community (Figure 4.5.4). Values for evenness may fall between 0 and 1. If all groups have a similar number of members, the community is very even, with an evenness value close to 1. Communities that have high evenness can remain more functional in stressful conditions than uneven communities (Wittebolle et al. 2009). A stream macroinvertebrate community may comprise many taxa, but even a very rich community can be in poor condition if there are few individuals belonging to sensitive taxa while there are many individuals from more hardy taxa. Evenness is likely to vary naturally among streams with different natural characteristics, so we referenced the literature and expert opinion to assign condition levels (L. Tronstad, personal communication, 27 January 2016). We used a quantile approach to assign condition to evenness scores. Values that were below the median (of a random distribution) were assigned the condition *Warrants Significant Concern*, values from the median up to the 75th percentile were classified as *Warrants Moderate Concern*, and values above the 75th percentile were assigned a *Good Condition* (Table 4.5.7).

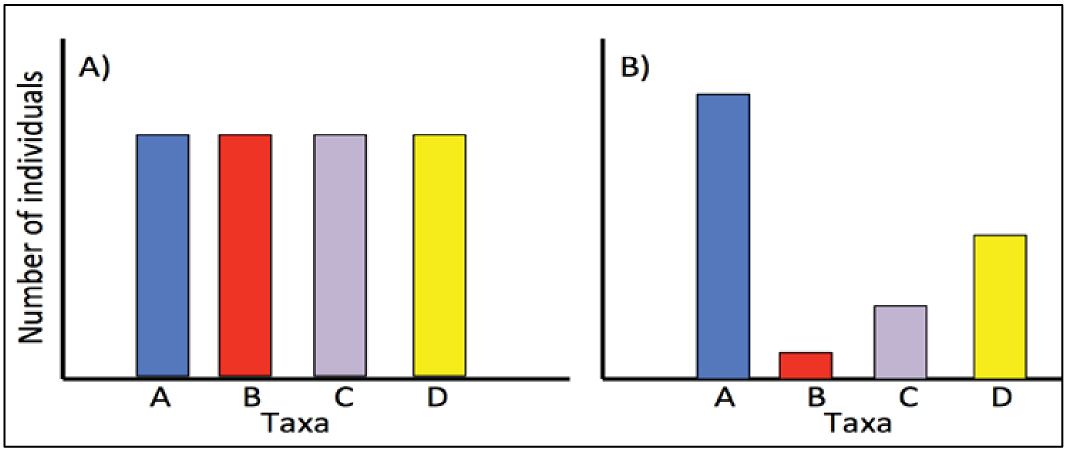


Figure 4.5.4. Illustration for describing taxa evenness. Taxa evenness is high if individuals are A) distributed similarly among taxa, and low if B) distributed unequally among taxa.

Table 4.5.7. Water quality condition categories for evenness.

Resource condition		**Evenness score**
Condition Icon Definition	**Condition Icon**	
Warrants significant concern	🔴	0 ≤ x ≤ 0.5
Warrants moderate concern	🟡	0.50 < x ≤ 0.75
Resource in good condition	🟢	0.75 < x ≤ 1

Indicator: Fecal Indicator Bacteria (Fecal Coliform)

Fecal coliform bacteria live in intestines of warm-blooded animals and are common biological contaminants of surface waters. Not all coliform bacteria are harmful, but the presence of some coliform bacteria can indicate the presence of pathogenic organisms (Gallagher and Spino 1968). Sampling for these bacteria is useful for assessing safety of drinking water and recreational water use (Geldreich 1970), as well as wildlands water quality (Bohn and Buckhouse 1985). *Escherichia coli* is a well-known fecal coliform that has been associated with illness following food contamination. Fecal coliform standards and testing in Nebraska surface waters (117 Nebraska Administrative Code § 81.1501 2014) are concerned primarily with *E. coli*.

Measure of Fecal Indicator Bacteria (Fecal Coliform): Escherichia coli (E. coli) Concentration

Concentration of *E. coli* (number of bacteria per unit volume) is regulated within single samples and within a 30-day period and must not exceed 126 colony-forming units (cfu)/100 milliliters (NE DEQ 2014). We used the geometric mean of at least five samples within 30 to calculate this value. In single samples, the concentration of this bacterium is also regulated to standards reflective of the amount that waterbodies are used for recreation (117 Nebraska Administrative Code § 81.1501 2014). If we did not have the requisite samples to apply a 30-day mean, we used the most conservative of the single sample standards to evaluate *E. coli* condition (Table 4.5.8). These standards do not apply to drinking water; fecal coliform must be absent from drinking water (0/100 milliliters).

Table 4.5.8. Water quality condition categories for *Escherichia coli* (*E. coli*).

Resource condition		***E. coli* concentration (cfu/100 milliliters)**
Condition Icon Definition	**Condition Icon**	
Warrants significant concern		126 ≤ x
Warrants moderate concern		100 < x ≤ 126
Resource in good condition		0 < x ≤ 100

<u>Data Sources</u>

Federal, state, and tribal governments monitor water quality using varying measures and monitoring durations. In this assessment we searched for data that were collected within the boundaries of

Agate Fossil Beds NM and, concurrent with DEQ water quality monitoring standards, downstream of the park in the Niobrara River. We conferred with experts to identify relevant monitoring data and reports for water quality at Agate Fossil Beds NM (D. Ihrie, personal communication, 21 Dec 2015). We identified multiple data sources within park boundaries: raw data collected from the Niobrara River, summary reports of water quality chemistry and biological indicators, and a thesis on water quality (Rust 2006). Data collected by Tronstad (2012a, 2012b, 2014, 2015a, 2015b) were the most recent, therefore forming the basis of our evaluation of water quality for all indicators except turbidity and fecal indicator bacteria. For these indicators we used data collected by Nebraska DEQ (2014) and Rust (2006), respectively.

Sampling locations that we considered for this assessment included points on the Niobrara River (Figure 4.5.5). Tronstand (2015) repeated sampling at three points on the river from June, 2010, through August, 2014. Rust sampled 10 points along the river three times between June, 2004, and July, 2005.

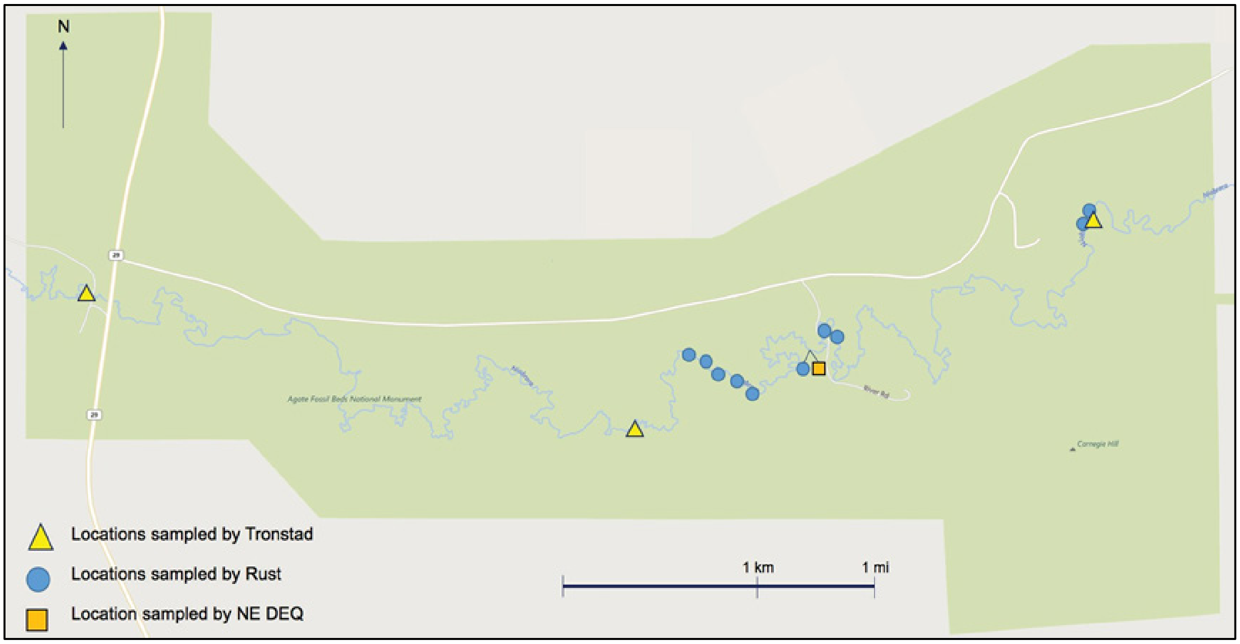


Figure 4.5.5. Water quality sampling locations along the Niobrara River at Agate Fossil Beds NM (modified from MyWATERS Mapper [EPA 2015]).

Quantifying Water Quality Condition, Confidence, and Trend

Indicator Condition

To quantify water quality condition and trend, we followed NPS methods for water quality assessment where applicable (Wilson and Wilson 2014). For measurements beyond the scope of NPS guidelines, we created condition categories based on expert opinion and the scientific literature. We deferred to data that were collected most recently and rigorously, where multiple sources existed. We used a point system to assign each indicator to a category. This point system is based on the NPS methods that were developed to calculate overall air quality condition (NPS-ARD 2015), a methodical and rigorous assessment approach that can be applied to other resources as well. In this approach, we assigned zero points to the condition *Warrants Significant Concern*, 50 points to *Warrants Moderate Concern*, and 100 points to *Resource in Good Condition*. The average of all measures determined the condition category of the indicator; scores from 0–33 fell in the *Warrants Significant Concern* category, scores from 34–66 were in the *Warrants Moderate Concern* category, and scores from 67–100 indicated *Resource in Good Condition*.

Indicator Confidence

Confidence ratings were based on monitoring location, monitoring frequency, and time since data collection. We gave a rating of *High* confidence when monitors or sampling efforts were on site, data were collected continuously for two years with the last year of sampling falling within two years of this assessment, and the data were collected using equipment and procedures consistent with published methods and NE DEQ standards. We assigned a *Medium* confidence rating when monitors and sampling efforts were located downstream, data were not collected recently, or data collection was not repeatable or methodical. We assigned *Low* confidence ratings when there were no good data sources to support the condition.

Indicator Trend

Potential trend categories were *Improving*, *Unchanging*, or *Deteriorating*. To calculate a trend estimate for core indicators and fecal indicator bacteria, we sought water quality data that were collected continuously for two years (Wilson and Wilson 2014). Data from ongoing NPS monitoring efforts will not be available until 2017, but we endeavored to identify a trend if other monitoring data were available. If there were no data available that met these monitoring requirements for a particular indicator, we indicated that trend was *Not Available* for that indicator. To calculate a trend for invertebrate indicators of water quality, we required at least three years of data in which samples had been collected

Overall Water Quality Condition, Confidence, and Trend

We used the general approach for combining indicator conditions, trends, and confidence described in Chapter 3 (Methods 3.2.2) to calculate overall resource condition, trend, and confidence (Table 4.5.9) at least twice.

Table 4.5.9. Summary of surface water quality indicators and measures.

Indicator	Measure	Condition	Confidence	Trend	Condition rationale
Acidity	pH	Good condition	Medium	Not available	Acidity was within state standards during sampling period. Monitoring was not continuous for two years, so confidence was *Medium* and trend was *Not Available*.
Dissolved oxygen (DO)	Milligrams/ liter	Warrants moderate concern	Medium	Not available	D.O. was within state standards during sampling period. Monitoring was not continuous for two years, so confidence was *Medium* and trend was *Not Available.*
Conductivity	Siemens/ meter	Good condition	Medium	Not available	Conductivity was within state standards during sampling period. Monitoring was not continuous for two years, so confidence was Medium and trend was Not Available.
Temperature	°Celsius	Warrants significant concern	Medium	Not available	Temperature was within state standards during sampling period. Monitoring was not continuous for two years, so confidence was Medium and trend was Not Available.

Table 4.5.9 (continued). Summary of surface water quality indicators and measures.

Indicator	Measure	Condition	Confidence	Trend	Condition rationale
Turbidity	Qualitative aesthetic assessment	Good condition	Medium	Not available	Turbidity was recently (2014) rated satisfactory in Niobrara River. Confidence was *Medium* and trend was *Not Available*.
Invertebrate assemblage	• HBI • EPT index • Proportion EPT • Evenness	Warrants significant concern	High	Deteriorating	The average score of conditions indicated by all measures was 25, which warranted *Significant Concern*. Monitoring was repeated annual for five years at three sites, using multiple methods. Confidence was *High* and trend was *Deteriorating*.
Fecal indicator bacteria	*Escherichia coli (E. Coli)* count of colony forming units/100 milliliters	Good condition	Medium	Not available	Coliform counts of *E. coli* were within state standards during sampling period. Monitoring was conducted during one year > 10 years prior to this assessment. Confidence was *Medium* and trend was *Not Available*.

4.5.4. Water Quality Conditions, Confidence, and Trends

The most recent invertebrate and core parameter data were collected in 2014 at three locations, each of which was sampled twice during the summer (Tronstad 2015a). Previous invertebrate sampling and core water quality data were collected in 2010, 2011, 2012, and 2013, all by Tronstad (2012a, 2012b, 2014, 2015a, 2015b). Fecal indicator bacterial levels were most recently collected by Rust (2006) from 10 sampling locations visited three times between June, 2004, and July, 2005. We referred to Nebraska DEQ report (2014) to obtain the turbidity aesthetic assessment.

<u>Acidity</u>

Condition: Resource in Good Condition
Confidence: Medium
Trend: Not Available

Condition

To assign a condition to acidity we used data summarized by Tronstad (2015a). All six samples collected from the Niobrara River in 2014 were within the acceptable range for pH (6.5–9.0) for Nebraska. These data placed acidity for Agate Fossil Beds NM in the *Good Condition* category.

Confidence

Acidity was calculated from pH data collected on site at Agate Fossil Beds NM and sampling was repeated within the season. The samples were collected fairly recently, but not continuously, so the confidence was *Medium*.

Trend

Acidity was calculated from pH data collected twice in a year within two years of this assessment, but were not collected continuously, so data were insufficient to identify a trend. Trend was *Not Available.*

<u>Dissolved Oxygen (DO)</u>

Condition: Warrants Moderate Concern
Confidence: Medium
Trend: Not Available

Condition

To assign a condition to dissolved oxygen (DO) we used data summarized by Tronstad (2015a). One of six samples collected from the Niobrara River in 2014 were not within the acceptable range for DO (≥ 5 milligrams/liter) for Nebraska. The percentage of samples that were not above the minimum required DO was 16.7%, which placed DO for Agate Fossil Beds NM in the *Warrants Moderate Concern* category.

Confidence

Dissolved oxygen was calculated from data collected on site at Agate Fossil Beds NM and sampling was repeated within the season. The samples were collected within two years, but not continuously, so the confidence was *Medium*.

Trend

Dissolved oxygen was calculated from data collected twice in a year, but not continuously, so data were insufficient to identify a trend. Trend was *Not Available*.

<u>Specific Conductivity</u>

Condition: Resource in Good Condition
Confidence: Medium
Trend: Not Available

Condition

To assign a condition to specific conductivity, we used data summarized by Tronstad (2015a). All six samples collected from the Niobrara River in 2014 were within the acceptable range (≤ 2,000

Siemens/meter) for Nebraska. These data placed DO for Agate Fossil Beds NM in the *Good Condition category.*

Confidence

Dissolved oxygen was calculated from data collected on site at Agate Fossil Beds NM and sampling was repeated within the season. The samples were collected within two years of this assessment, but not continuously, so the confidence was *Medium*.

Trend

Dissolved oxygen was calculated from data collected twice in a year, but not continuously, so data were insufficient to identify a trend. Trend was *Not Available*.

<u>Temperature</u>

Condition: Warrants Significant Concern Confidence: Medium Trend: Not Available

Condition

To assign a condition to temperature, we used data summarized by Tronstad (2015a). Two of six samples collected from the Niobrara River in 2014 were not within the acceptable range (≤ 22 °C) for Nebraska. The percentage of samples that were not below the maximum allowed temperature was 33.3%, which placed DO for Agate Fossil Beds NM in the *Warrants Significant Concern* category.

Confidence

Temperature was calculated from data collected on site at Agate Fossil Beds NM and sampling was repeated within the season. The samples were collected within two years of this assessment, but not continuously, so the confidence was *Medium*.

Trend

Temperature was calculated from data collected twice in a year, but not continuously, so data were insufficient to identify a trend. Trend was *Not Available*.

<u>Turbidity</u>

Condition: Resource in Good Condition Confidence; Medium Trend: Not Available

Condition

To assign a condition to turbidity, we reviewed the most recent Nebraska Water Quality Integrated Report (NE DEQ 2014) and searched for records of aesthetic impairment of surface waters considered in this assessment. Nebraska DEQ evaluated aesthetics of the Niobrara River and found the aesthetics were satisfactory, so turbidity was in *Good Condition*.

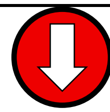
Confidence

We assigned turbidity condition based on Nebraska DEQ assessment of surface water aesthetics in the Niobrara River. The assessment was conducted on site recently, but turbidity conditions could vary seasonally; in the absence of background data, the confidence was *Medium*

Trend

Turbidity data were insufficient to identify a trend. Trend was *Not Available*.

<u>Invertebrate Assemblage</u>



Condition: Warrants Significant Concern
Confidence: High
Trend: Deteriorating

Condition

We used data collected by Tronstad (2015a) to assign a condition to invertebrate assemblage. To calculate overall indicator condition from the four measures, we used the average condition indicated by each measure.

- **Hilsenhoff Biotic Index (HBI):** We were careful to separate two methods (Hester-Dandy and Hess) that Tronstad used, but both methods gave the same general conditions for this assessment. Average values of HBI were 5.9 and 6.2, sampled using the Hester-Dandy and Hess methods, respectively. Using the most conservative score, these results indicated an HBI condition of *Warrants Significant Concern* at Agate Fossil Beds NM.
- **EPT Index:** Average values of EPT index were 3.73 and 4, sampled using the Hess and Hester-Dandy methods, respectively. These results indicated an EPT index condition of *Warrants Significant Concern* at Agate Fossil Beds NM.
- **Proportion EPT:** Average values for proportion EPT of total invertebrate samples were 0.13 and 0.21, sampled using the Hess and Hester-Dandy methods, respectively. These results indicated a proportion EPT condition of *Warrants Significant Concern* at Agate Fossil Beds NM.
- **Evenness:** Average values for evenness were 0.62 and 0.71, sampled using the Hess and Hester-Dandy methods, respectively. These results indicated an evenness condition of *Warrants Moderate Concern* at Agate Fossil Beds NM. The average of conditions indicated by all measures was 25, which placed the condition of macroinvertebrate assemblage at Agate Fossil Beds NM in the category, *Warrants Significant Concern*.

Confidence

Macroinvertebrate data were collected on site at Agate Fossil Beds NM at three locations, twice a year, for five consecutive years. Because macroinvertebrate condition reflects long term environmental conditions, unlike the snapshots nature of chemical sampling, this sampling schedule was sufficient to indicate water quality. Confidence was *High*.

Trend

Macroinvertebrate measures were calculated from data collected at three locations, twice a year, for five consecutive years. Tronstad (2015a) compiled invertebrate data from previous years (Figure 4.5.6) and identified that HBI had increased, EPT richness had decreased, and percentage of EPT had decreased since 1989—these changes were indicative of deteriorating invertebrate community. Trend was *Deteriorating*.

<u>Fecal Indicator Bacteria (Fecal Coliform)</u>

Condition: Resource in Good Condition
Confidence: Medium
Trend: Not Available

Condition

To assign a condition to fecal coliform bacteria, we used data summarized by Rust (2006). All three coliform count samples were within the maximum allowed coliform count (126 colony forming units/100 milliliters). These data placed the fecal bacteria indicator for Agate Fossil Beds NM in the *Resource in Good Condition* category.

Confidence

Fecal indicator bacteria condition was calculated from data collected on site at Agate Fossil Beds NM, but data were collected for only one year over 10 years prior to this report. Fecal indicators can be highly variable with stream turbidity and flow, so confidence would improve with a comparison between those variables, as well as with repeated and more recent sampling. Confidence for fecal indicator bacteria was *Medium*.

Trend

Fecal coliform data were collected in one year, so data were insufficient to identify a trend. Trend was *Not Available*.

<u>Water Quality Overall Condition</u>

Condition

Overall water quality condition was determined by the average of the indicator conditions (Table 4.5.10). We summarized the condition, confidence, and trend for each indicator, and assigned condition points. The total score for overall water quality condition was 64 points, which placed water quality at Agate Fossil Beds NM in the *Warrants Moderate Concern* category.

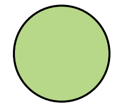
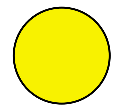
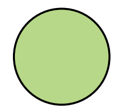
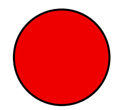
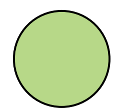
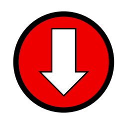
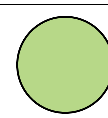
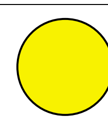
Confidence

Confidence was Low for Turbidity and Medium for all other indicators. The score for overall confidence was 57 points, which met the criteria for *Medium* confidence in overall water quality.

Trend

Trend data were not available for any indicator, so overall trend for water quality was *Not Available.*

Table 4.5.10. Water quality overall condition.

Indicators	Measures	Condition
Acidity	• pH	
Dissolved oxygen	• mg/L	
Specific Conductivity	• Siemens/meter	
Temperature	• °C	
Turbidity	• NTUs	
Invertebrate assemblage	• HBI • EPT index • % EPT • Evenness	
Fecal indicator bacteria	• *E. coli* concentration	
Overall condition for all indicators and measures		

4.5.5. Stressors

One likely stressor of water quality condition in the Niobrara River is yellow flag iris (*Iris pseudacorus*), which has heavily invaded the banks of the river (Spurgeon et al. 2014, Tronstad 2015a). Yellow flag iris is one of the most common plants at Agate Fossil Beds NM and, in 2013, accounted for > 10% of total cover and 14% of riparian cover (Prowatzke and Wilson 2015). Decomposing iris could decrease DO, especially in the winter when the plants die back, and DO could also decrease when the river overflows into the floodplain (L. Tronstad, personal communication, 27 April 2016). The iris could be contributing to a narrowing of the channel, as well as slowing the flow rate (L. Tronstad, personal communication, 27 April 2016); the effect of these changes could be increased sedimentation and temperature. Chemical and physical changes to the stream caused by the iris could affect macroivertebrate community composition, and probably the fish as well. An invasion of the Niobrara River by northern pike (*Esox lucius*) from downstream stock ponds could also have affected the invertebrate community (Spurgeon et al. 2014).

Additionally, the recent development of the Bakken shale oil poses a significant industrial threat to water supply competitive demand and water quality, in the general region (P. Penoyer, personal communication 7 July 2016).

4.5.6. Data Gaps

Water quality data for core indicators at Agate Fossil Beds NM were limited to samples collected three times a year, and continuous sampling is required for any more detailed analysis of trend. Continuous sampling within the park for at least two years would improve assessment efforts to understand the water quality condition at Agate Fossil Beds NM. A variety of potential sampling schemes would provide NPS with sufficient data to evaluate trends in water quality over time (Wilson et al. 2014), although the best one for Agate Fossil Beds NM will depend on the specific objectives of NPS management.

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- Pete Penoyer (NPS)

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4.6. Geology

Rocky outcrop at Agate Fossil Beds NM (NPS photo).

4.6.1. Background and Importance

Geological resources underlie and affect many other resources within National Park System units. Their characteristics and qualities, such as general rock type, mineral content, grain size, porosity and permeability, and friability (ability for rock to be reduced to smaller pieces) determine the location and stability of other park resources. Topography, slope stability, surface- and groundwater flow patterns, soil types, vegetation, and human use patterns are all affected by underlying geology.

In the northern Great Plains area, most of the bedrock is composed of soft Upper Cretaceous and Tertiary sedimentary strata. Many of these rocks are rich in swelling clays, which can make them highly friable and lead to slope instability. Modern river valleys in this region hold thick fluvial gravel deposits that overlie the sedimentary bedrock. In many areas these river gravels have shaped the history of human habitation, as buildings were historically placed near the river channels (Graham 2009b).

Geological hazards in the northern Great Plains area are mostly related to mass wasting activity, as the soft, clay-rich bedrock is often prone to slumps, slides, and rockfalls. While events such as these are natural, various land uses and human activities can affect the magnitude and rate of mass wasting activities. For this reason and because of the potential danger to visitors, NPS places a high priority on managing key locations within park to minimize uncharacteristic or dangerous mass wasting events.

The Great Plains region has not been seismically active for millions of years and earthquakes are uncommon in the area, although small earthquakes have occurred in the northern Laramie Range in Wyoming approximately 129 kilometers (80 miles) west of Agate Fossil Beds NM, and also near Guernsey, WY, approximately 80 kilometers (50 miles) to the southwest (Case 2002).

<u>Regional Context</u>

Surface and subsurface strata of the Great Plains physiographic province represent many different paleoenvironments spanning millions of years. While older rocks are present in the subsurface, the oldest rocks exposed within Agate Fossil Beds National Monument are those of the Harrison Formation, a subdivision of the Arikaree Group of Miocene age.

The Tertiary strata of the northern Great Plains are an important sequence of rocks, in that they hold the best-preserved record of a climactic transition and its aftermath in the terrestrial rock record (Prothero 1994). This transition, termed the Eocene–Oligocene climate transition (EOT), records gradual changes from generally warmer and wetter to cooler and drier conditions. During this time the change in environmental conditions reduced forest cover and correspondingly increased open grasslands, as reflected in fossil soils. These deposits stretch for hundreds of miles across the region. Because differential erosion across the region has removed some parts of the Eocene and Oligocene strata and left others in place, outcrops across the area preserve different segments of the EOT (Prothero and Emry 2004).

The strata exposed at the surface in Agate Fossil Beds National Monument preserve the end of this transition when the open grasslands were fully in place (Benton et al. 2015). These rock units, the Harrison Formation and the overlying "Anderson Ranch Formation" of the Arikaree Group, both contain abundant vertebrate fossils indicative of grasslands including: birds; perissodactyls such as rhinoceros, tapirs, and horses; artiodactyls such as camels, oreodonts, and entelodonts ("hell pigs"); and carnivores such as early canids, bears, and mustelids (Graham, 2009a). The Arikaree Group here is late Oligocene to Miocene in age (~28.5–26 million years ago) (Tedford et al. 2004). At Agate Fossil Beds NM, four main quarries have yielded many fossils representative of the fauna of the Arikaree Group (Benton et al. 2015).

A major attraction at Agate Fossil Beds NM are the Fossil Hills (Figure 4.6.1), also known as Carnegie Hill. There are no current fossil collecting activities at Carnegie Hill, but visitors can see fossils collected at this quarry and others on display in the visitor center. At one time, exhibit cases were used to showcase in situ fossils at Carnegie Hill, but they were removed in the 1990s due to danger from rockfalls and vandalism (NPS 2011; Graham 2009a).

Even without active fossil collection, the Fossil Hills are still an important geologic resource for Agate Fossil Beds NM as they are the area most identified with the park and are shown in many images of the monument (e.g., Figure 4.6.1). This cliff of exposed bedrock also provides an excellent example of the geology of the monument and the surrounding region and is, therefore, a valuable tool for interpretation of the geologic history of the area (R. Hunt, personal communication, 4 April 2016).

Figure 4.6.1. The Fossil Hills, Agate Fossil Beds National Monument (NPS photo).

4.6.2. Geology Standards

No federal or state regulations exist to protect geological resources. Paleontological resources on federal lands are protected under several laws and rulings, including the National Environmental Policy Act of 1969 (P.L. 91–190; 31 Stat. 852, 42 U.S.C. 4321–4327); the Federal Land Policy and Management Act of 1976 (P.L. 94–579; 90 Stat. 2743, U.S.C. 1701–1782); and most recently the Omnibus Public Land Management Act of 2009 (PL 111–11, Title IV, Subtitle D—Paleontological Resources Protection). These federal guidelines were put in place to protect fossil resources from destruction by various types of human activities, including theft and ground disturbance during construction.

4.6.3. Methods

Indicators and Measures

Overall geological resource condition in Agate Fossil Beds National Monument depends on the condition of a single indicator, weathering/erosion; we considered weathering and erosion together because they work in tandem to break down and remove geologic material. Preservation of paleontological resources is also an issue of concern at Agate Fossil Beds NM (Graham 2009a), and it is discussed in detail in the section on Paleontological Resources in this NRCA.

Indicator: Weathering and Erosion

Weathering and erosion together have been identified as important geologic resource issues within Agate Fossil Beds National Monument (Graham 2009a). Weathering is defined as the breaking down of minerals within a rock by chemical and/or mechanical means, while erosion is the movement of that weathered material away from its place of origin (Press and Siever 2001).

In Agate Fossil Beds NM, weathering and erosion affect the condition of geologic resources in Agate Fossil Beds National Monument. The strata that are exposed within the Monument, the Harrison Formation and the overlying "Anderson Ranch" Formation of the Miocene-aged Arikaree Group, consist mainly of unconsolidated sandstone and volcanic ash (Graham 2009a; Hunt 1990). These strata are easily weathered, and wind and summer rainstorms erode the weathered sediment (R. Hunt, personal communication, 4 April 2016).

To assign a condition to this indicator, we used qualitative information about weathering and erosion in general as well as weathering and erosion that has impacted the main fossil quarry at Carnegie Hill due to human activities there.

Measure of Weathering and Erosion: Amount of Erosion (millimeters/year)

Weathering caused by the actions of water and ice is breaking down the bedrock that crops out at Agate Fossil Beds NM. This weathered material is then removed from that surface by erosion via wind and water. In many areas, geologists are not able to easily measure background rates of weathering and erosion over short timespans such as years or decades because rates are often on the order of fractions of a millimeter per year (Burbank 2002). As a result, we often do not have a good understanding of how quickly exposed bedrock is weathering and eroding on human timescales. Recent advances in the use of cosmogenic nuclides (nuclides created by the interaction of cosmic rays with materials on Earth's surface) for measuring weathering and erosion rates have helped our understanding of these rates (Granger and Riebe 2014), although these types of studies have not been done in Agate Fossil Beds NM nor in other areas where the same formations are exposed.

Other less-technical methods of measuring weathering and erosion have been used in other park units. In the 1950s, metal U.S. Geodetic Survey markers were emplaced flush with the ground surface in several places across Badlands National Park, and over the past 60+ years weathering and erosion have removed bedrock from around the markers. Thus, the amount of weathering and erosion that has occurred since the markers were placed can be directly measured in that part of the Badlands (Benton et al. 2015). Similarly, in 1933 a metal survey marker was emplaced in the strata of the Monroe Creek-Harrison formations (undivided) at the top of Scotts Bluff in Scotts Bluff National Monument. Weathering and erosion of bedrock around the marker over the past 83 years has left the marker exposed, allowing the rate of weathering and erosion of the summit of Scotts Bluff to be measured (Graham 2009b). No such markers have ever been placed in Agate Fossil Beds NM.

Different types of bedrock weather at different rates as a result of their composition as well as the environmental conditions to which they are exposed (Press and Sevier 2001). The Harrison and "Anderson Ranch" formations that are exposed at Agate Fossil Beds NM consist mainly of unconsolidated sandstone and volcanic ash that weathers quickly (Graham 2009a; Hunt 1990). While rates of erosion specific to these rocks are not reported, we can use data from equivalent strata elsewhere to get approximate rates of erosion that would be expected under natural conditions for the rocks that crop out within Agate Fossil Beds NM.

Erosion around metal survey markers at the top of Scotts Bluff shows that the rate of weathering and erosion of the Monroe Creek–Harrison formations (undivided) is approximately 0.36

millimeters/year (Graham 2009a). This rate can be applied to the strata of the equivalent Harrison Formation strata that are exposed in Carnegie Hill, as both areas have similar rock exposed in a hill or bluff (Hunt 1990). This rate of weathering and erosion can be used as the rate expected for the strata at Agate Fossil Beds NM under natural conditions.

If the rate of weathering and erosion of the strata at Agate Fossil Beds NM is outside of the expected natural conditions by an order of magnitude (< than 0.036 millimeters/year or > than 3.6 millimeters/year) we assigned the condition *Warrants Significant Concern*, meaning that the resource is behaving outside of natural conditions. If weathering and erosion was slightly outside of the expected natural conditions (0.036–0.36 millimeters/year, or > 3.6 millimeters/year), we assigned the condition *Warrants Moderate Concern*, meaning that the resource is behaving somewhat outside of natural conditions. If weathering and erosion was consistent with the rates measured in the Monroe Creek – Harrison formations (undivided) at Scotts Bluff, we assigned the highest level of condition, *Resource in Good Condition*, meaning that the resource is behaving within natural conditions (Table 4.6.1).

Table 4.6.1. Geologic resource condition categories for amount of erosion.

Resource condition		
Condition Icon Definition	**Condition Icon**	**Erosion rate (mm/yr)**
Warrants significant concern		< 0.036 or > 3.6
Warrants moderate concern		0.036 ≤ x < 0.36 or > 0.36
Resource in good condition		0.36

Measure of Weathering and Erosion: Mass Wasting

Mass wasting, the geologic process of sediment, rock, and soil moving downslope, is an important geologic resource issue at Agate Fossil Beds NM. Mass wasting is a natural process that occurs as a result of water, ice, and/or wind acting on loosely consolidated strata that then fail under the pull of gravity. Mass wasting also can be exacerbated by human activities such as exposing rock during fossil quarrying work. Mass wasting results in the degradation of the geologic resource itself, and as such, is a resource concern.

Rockfalls are the main type of mass wasting that occurs at Agate Fossil Beds NM (Graham 2009a). The excavation of the principle fossil quarry at Carnegie Hill has created a vertical cliff, which is then eroded by wind, removing soft rock and leaving the more consolidated rock above unsupported. Over time, this results in collapse of the upper part of the cliff (R. Hunt, personal communication, 4 April 2016). No measurements have been used to quantify the amount of debris produced or the frequency of rockfalls; we can, however, use observations of rockfalls to make qualitative assessments of this measure. If human-caused rockfalls occurred regularly, we assigned the condition W*arrants Significant Concern*, meaning the resource is behaving outside of natural conditions. If human-caused rockfalls occurred occasionally, meaning the resource is behaving somewhat outside of natural conditions, we assigned the condition *Warrants Moderate Concern*. We gave the highest level of condition, *Resource in Good Condition*, if there were no human-caused rockfalls (Table 4.6.2).

Table 4.6.2. Geologic resource condition categories for mass wasting.

Resource condition		Consistency of natural range of variation
Condition Icon Definition	**Condition Icon**	
Warrants significant concern	Red circle	Human-caused rockfalls occur regularly: resource behaving outside natural conditions
Warrants moderate concern	Yellow circle	Human-caused rockfalls occur occasionally: resource behaving somewhat outside natural conditions
Resource in good condition	Green circle	No human-cause rockfalls occur: resource is behaving within expected natural conditions

Data Sources

Much of the information summarized here was presented in a Geologic Resources Inventory Report prepared for the National Park Service (Graham 2009a). Other sources of information include scientific papers and books that we identify throughout this assessment. No fieldwork was performed for this summary.

No quantitative data were available on weathering and erosion at Agate Fossil Beds National Monument; instead, we referred to qualitative data on weathering and erosion as well as occurrences of rockfalls at the main fossil quarry from park and researcher reports to assess indicator quality.

Quantifying Geologic Condition, Confidence, and Trend

Indicator Condition

To quantify geologic condition and trend, we used qualitative data, expert opinion, and reports of prior impacts to the resource, as described above. For measurements beyond the scope of NPS guidelines, we created condition categories based on expert opinion and the scientific literature. We used a point system to assign each indicator to a category. This point system is based on the NPS methods that were developed to calculate overall air quality condition (NPS-ARD 2015), a methodical and rigorous assessment approach that can be applied to other resources as well. In this approach, we assigned zero points to the condition *Warrants Significant Concern*, 50 points to *Warrants Moderate Concern*, and 100 points to *Resource in Good Condition*. The average of all measures determined the condition category of the indicator; scores from 0–33 fell in the *Warrants Significant Concern* category, scores from 34–66 were in the *Warrants Moderate Concern* category, and scores from 67–100 indicated *Resource in Good Condition*.

Indicator Confidence

Confidence ratings were based on availability and type of data collected about the indicator. We gave a rating of *High* confidence when quantitative data were collected on site or nearby under similar conditions or in similar strata, quantitative data were collected recently, and quantitative data were collected methodically. We assigned a *Medium* confidence rating when quantitative data were not collected nearby, quantitative data were not collected recently, quantitative data collection was not repeatable or methodical, or data were qualitative only. *Low* confidence ratings were assigned when there were no valid data sources to support the condition.

Indicator Trend

Potential trend categories were *Improving*, *Unchanging*, or *Deteriorating*. Because of the long timescales that are involved in many geologic processes as well as the complex interactions between geology and other natural processes such as precipitation, it is often difficult or impossible to see true trends in the condition of a geologic resource. To calculate a trend estimate for indicators, we sought quantitative or qualitative data that were collected at least sporadically for as long as the park unit has formally existed; in the case of Agate Fossil Beds this time period is 50 years (Graham 2009a). If there were no data available that met these monitoring requirements for a particular indicator, we indicated that trend was *Not Available* for that indicator.

Overall Geologic Condition, Confidence, and Trend

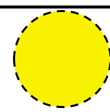
We used the general approach for combining indicator conditions, trends, and confidence described in Chapter 3 (Methods 3.2.2) to calculate overall resource condition, trend, and confidence (Table 4.6.3).

Table 4.6.3. Summary of geologic resource indicators and measures.

Indicator	Measure	Condition	Confidence	Trend	Condition rationale
Weathering and erosion	Amount of weathering and erosion	Not available	Low	Not available	Direct measurements of the rates of weathering and erosion are not available at Agate Fossil bed NM due to a lack of data. This gives this measure a condition of *Not Available.*
	Mass wasting events	Warrants moderate concern	Low	Not available	Rockfalls at the main fossil quarry in Agate Fossil Beds NM degrade the geologic resource. This assessment places mass wasting in the *Warrants Moderate Concern* category. There were no on-site quantitative data available for either measure, so confidence was *Low*. Trend was *Not Available.*

4.6.4. Geology Conditions, Confidence, and Trends

<u>Weathering and Erosion</u>



Condition: Warrants Moderate Concern
Confidence: Low
Trend: Not Available

Condition

Because of the type of rock that crops out at Agate Fossil Beds National Monument, weathering and erosion are major factors in the condition of geologic resources (Graham 2009a). We used two measures of weathering and erosion to assess its condition: the amount of weathering and erosion occurring, and the occurrence of mass wasting at the main fossil quarry on Carnegie Hill.

In both Badlands NP and Scotts Bluff NM, measureable rates of weathering and erosion for exposed bedrock come from metal survey markers that were emplaced flush with the bedrock surface and are now exposed. Unfortunately, no such markers exist in Agate Fossil Beds NM, nor does any other data source report rates of weathering and erosion in the park. As a result, we are unable to quantify either the amount of weathering and erosion that has historically taken place or the rates of weathering and erosion in Agate Fossil Beds NM. We therefore assigned a condition of *Unknown* for the measure of the amount of weathering and erosion of exposed bedrock.

Excavation of the main fossil quarry at Carnegie Hill began in 1905, and during that time removal of the rock matrix has resulted in a large cliff approximately 50 feet high on the southwest side of the hill. These strata are now exposed to the elements, and wind erosion of the underlying soft sandstone undercuts the more consolidated strata above, leaving them unsupported and prone to collapse (Graham 2009a; R. Hunt, personal communication, 4 April 2016).

The mass wasting of the cliff at the main fossil quarry on Carnegie Hill is mainly the result of human actions on the geologic resource. As a result, even though mass wasting is a natural process, the resource is behaving outside of natural conditions due to human activities. We therefore assigned a condition of *Warrants Moderate Concern* for the measure of mass wasting at the main fossil quarry. We used the single measure for which we had a condition to assign the indicator condition.

Confidence

There were no quantitative data available on either amounts of weathering and erosion or mass wasting in Agate Fossil Beds NM, therefore we gave both measures a confidence rating of *Low*. The overall confidence for the indicator of weathering/erosion is *Low* due to the lack of qualitative data for both measures.

Trend

Trend was *Not Available* for the measures of rates of weathering and erosion and mass wasting, so trend was *Not Available* for the indicator of weathering/erosion.

Geologic Resource Overall Condition

Condition

The overall geologic resources condition was determined by the condition of the single indicator, weathering/erosion (Table 4.6.4). Weathering/erosion was given a condition of *Warrants Moderate Concern*, which placed the overall geologic resource condition for Agate Fossil Beds NM in the category *Warrants Moderate Concern*.

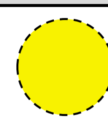
Confidence

Confidence was low for the single indicator of weathering/erosion, so overall confidence was *Low* for geologic resources.

Trend

Trend data were not available for the single indicator of weathering/erosion, so overall trend for geologic resources was *Not Available*.

Table 4.6.4. Geological resources overall condition.

Indicators	Measures	Condition
Weathering and erosion	• Amount of weathering and erosion • Mass wasting events	

4.6.5. Stressors

One potential stressor to geological resources was identified: the timing and amounts of precipitation events. As demonstrated by Stetler (2014), individual heavy precipitation events can significantly increase the rate of short-term weathering and erosion of fossil-bearing strata. It has been predicted that climate change may result in an increase in the numbers of these extreme precipitation events for Badlands NP, and this would in turn increase the impact of weathering and erosion on geologic resources (Amberg et al. 2012).

4.6.6. Data Gaps

One data gap is recognized for geologic resources at Agate Fossil Beds National Monument: the lack of quantitative data on geologic resource issues of the park. Long-term monitoring data on weathering and erosion in general as well as the frequency and size of rockfalls at the fossil quarries would be useful in future assessments of the condition of geologic resources at Agate Fossil Beds National Monument.

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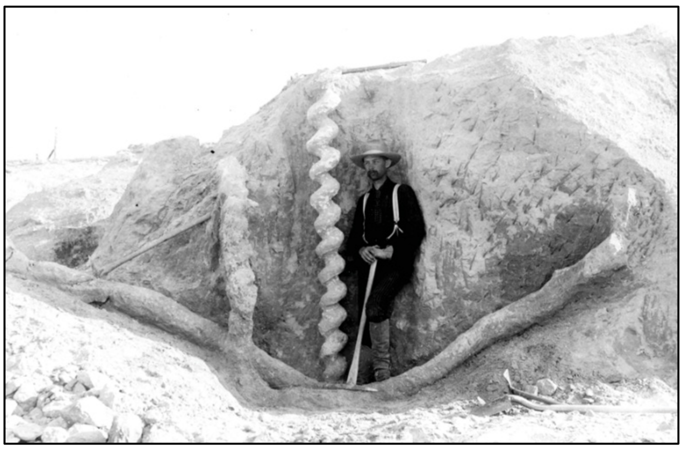
4.7. Paleontological Resources

4.7.1. Background and Importance

The principal mission of the National Park Service is the preservation, protection, and stewardship of natural and historic resources. Fossils, and the natural geologic processes that form, preserve, and expose them are included in this mission (NPS 2016). Paleontological resources are non-renewable, and they hold the keys to understanding the complex history of life on Earth. They are known from 260 NPS units, and they are the main resource showcased in 13 of those parks, including Agate Fossil Beds National Monument (NPS 2016). The fossil resources of Agate Fossil Beds NM include the first major accumulations of terrestrial vertebrate fossils of late Eocene and early Oligocene age discovered in North America (Graham 2009a).



Daemonelix burrow, or "Devil's corkscrew," in Agate Fossil Beds NM (Historic photo, Wikimedia Commons).

Paleontological resources are defined in the Paleontological Resources Preservation Act (2009) as "any fossilized remains, traces, or imprints of organisms, preserved in or on the earth's crust, that are of paleontological interest and that provide information about the history of life on Earth … " excluding archaeological and cultural resources. The distribution of paleontological resources is directly related to the distribution of sedimentary geologic units exposed on the ground surface, and this relationship allows prediction of fossil potential on a landscape-wide scale.

In the northern Great Plains area, most of the fossiliferous bedrock deposits represent two general time periods and environments: the Late Cretaceous Western Interior Seaway, with remains of invertebrates such as ammonites and vertebrates such as bony fish, sharks, and marine reptiles; and the Tertiary terrestrial deposits of Oligocene and Miocene age that record the spread of grasslands across the region and the rise of large grazing mammals.

Regional Context

Surface and subsurface strata of the Great Plains physiographic province represent many different paleoenvironments spanning millions of years. While older rocks are present in the subsurface, the oldest rocks exposed within Agate Fossil Beds National Monument are those of the Harrison

Formation, a subdivision of the Arikaree Group of Oligocene age. Overlying these strata are the beds of the Upper Harrison Formation, also termed the "Anderson Ranch" Formation (Hunt 1990).

The Tertiary strata of the northern Great Plains are an important sequence of rocks, in that they hold the best-preserved record of a climactic transition and its aftermath in the terrestrial rock record. This transition, termed the Eocene–Oligocene climate transition (EOT), records gradual changes from generally warmer and wetter to cooler and drier conditions. During this time the change in environmental conditions resulted in a reduction in forested areas and a corresponding increase in open grasslands as reflected in fossil soils (Prothero 1994).

These deposits stretch for hundreds of miles across the region, with different parts of the area recording different segments of the EOT. The strata exposed at the surface in Agate Fossil Beds National Monument preserve the end of this transition, when the open grasslands were in fully in place (Benton et al. 2015).

The fossil-bearing rock units that crop out in the park, the Harrison Formation and the overlying "Anderson Ranch Formation" of the Arikaree Group, both contain abundant vertebrate fossils indicative of grasslands including: birds; perissodactyls such as rhinoceros, tapirs, and horses; artiodactyls such as camels, oreodonts, and entelodonts ("hell pigs"); and carnivores such as early canids, bears, and mustelids (Graham, 2009a). In addition, a unique trace fossil is known from Agate Fossil Beds NM: the preserved burrow of the early beaver *Paleocastor*. The burrow itself is termed Daemonelix, "Devil's Corkscrew" and was initially thought to be the remnants of a cavity formed by a giant taproot (Graham 2009a). Arikaree Group here is late Oligocene to Miocene in age (~28.5–26 million years ago; Tedford et al. 2004).

4.7.2. Paleontological Resources Standards

Paleontological resources on federal lands are protected under several laws and rulings, including the National Environmental Policy Act of 1969 (P.L. 91–190, 31 Stat. 852, 42 U.S.C. 4321– 4327); the Federal Land Policy and Management Act of 1976 (P.L. 94–579, 90 Stat. 2743, 43 U.S.C. 1701–1782); and most recently the Omnibus Public Land Management Act of 2009 (PL 11–11, Title IV, Subtitle D—Paleontological Resources Protection). These Federal guidelines were put in place to protect fossil resources from destruction by various types of human activities, including theft and ground-disturbance during construction.

4.7.3. Methods

Indicators and Measures

Overall paleontological resource condition at Agate Fossil Beds National Monument depends on the condition of a single indicator, fossil loss.

Indicator: Fossil Loss

As non-renewable resources, the loss of fossils from National Park Service units is a very important resource issue. Fossils can be lost through natural processes as well as from human impacts. Weathering, defined as the breaking down of minerals within a rock (or a fossil) by chemical and/or mechanical means, and erosion—the movement of weathered material away from its place of origin

—are natural processes that can negatively impact fossil resources (Press and Siever 2001; Benton et al. 2015). Poaching of fossils from park by people also results in the loss of fossil resources.

To assign a condition to this indicator, we used qualitative and quantitative information about fossil loss, including weathering and erosion of rock and its contained fossils, as well the amount of poaching of fossils that has been documented within the park.

Measure of Fossil Loss: Amount of Weathering and Erosion of Rock (millimeters/year)

In Agate Fossil Beds National Monument, weathering and erosion act together to impact paleontological resources. Fossils are continually being exposed as a result of weathering and erosion, and this can result in physical degradation of the fossils, damage due to accidental or intentional breakage, and theft (Benton et al. 2015; Stetler 2014).

The rate at which fossils weather out of their containing strata and become exposed to the elements depends mainly on the type of rock they are preserved in, and so rates of weathering of those rocks play a large role in the loss of fossil resources.

In many areas, geologists are not able to easily measure background rates of weathering and erosion over short timespans such as years or decades because rates are often on the order of fractions of a millimeter per year (Burbank 2002). As a result, we often do not have a good understanding of how quickly exposed bedrock is weathering and eroding on human timescales. Recent advances in the use of cosmogenic nuclides (nuclides created by the interaction of cosmic rays with materials on Earth's surface) for measuring weathering and erosion rates have helped our understanding of these rates (Granger and Riebe 2014), although these types of studies have not been completed in Agate Fossil Beds NM nor in other areas where the same formations are exposed.

Other less-technical methods of measuring weathering and erosion have been used inother park units. Metal markers were emplaced in two park units in the region, and years of weathering and erosion have removed bedrock from around the markers. Thus, the amount of weathering and erosion that has occurred since the markers were placed can be directly measured (Graham 2009). No such markers have ever been placed in Agate Fossil Beds NM.

Different types of bedrock weather at different rates as a result of their composition as well as the environmental conditions they are exposed to (Press and Sevier 2001). The Harrison and "Anderson Ranch" formations that are exposed at Agate Fossil Beds NM consist mainly of unconsolidated sandstone and volcanic ash that weathers quickly (Graham 2009a; Hunt 1990). While rates of erosion specific to these rocks are not reported, we can use data from equivalent strata elsewhere to get approximate rates of erosion that would be expected under natural conditions for the rocks that crop out within Agate Fossil Beds NM.

Based on the above-mentioned metal survey marker at the top of Scotts Bluff, the rate of weathering and erosion of the Monroe Creek – Harrison formations (undivided) is approximately 0.36 millimeters/year (Graham 2009a). This rate can be applied to the strata of the equivalent Harrison Formation strata that are exposed in Carnegie Hill, as both areas have similar rock exposed in a hill or bluff (Hunt 1990). This rate of weathering and erosion can be used as the rate expected for the strata at Agate Fossil Beds NM under natural conditions.

Recent work in Badlands National Park has focused on erosion rates that specifically impact fossil resources. Between 2011 and 2013, measurements of weathering and erosion of fossil-bearing strata were collected using a combination of direct measurements of the amount of material removed, digital imaging, and measurements of the amount of rainfall received on the strata. These measurements allow assessments of the actual amount of impact that weathering and erosion are having on fossil-bearing strata.

If weathering and erosion has been occurring at a rate that negatively impacts fossil resources, we assigned the condition *Warrants Significant Concern*. If weathering and erosion was moderate, and fossil resources were only moderately impacted, we assigned the condition *Warrants Moderate Concern*. If there was no weathering or erosion OR any weathering and erosion was at a low level, we assigned the highest level of condition, *Resource in Good Condition* (Table 4.7.1).

Table 4.7.1. Paleontological resources condition categories for amount of erosion.

Resource condition		Impact of weathering/erosion
Condition Icon Definition	**Condition Icon**	
Warrants significant concern	(red circle)	Weathering and erosion is occurring at a rate that negatively impacts fossil resources
Warrants moderate concern	(yellow circle)	Weathering and erosion is moderate and somewhat impacts fossil resources
Resource in good condition	(green circle)	No weathering or erosion has occurred OR any weathering and erosion is at a low level

Measure of Fossil Loss: Amount of Fossil Poaching

Poaching and vandalism of fossils from Federal lands is an important cause of the loss of paleontological resources. Fossils are objects of interest and are unique and often coveted. The increasing economic value of fossils, spurred by the sale of a *Tyrannosaurus rex* fossil for more than $8 million in 1997, puts paleontological resources on public lands at risk for permanent loss (Eveleth 2013; Beat and Hanna 2009).

Fossil poaching can take many forms. For example, the casual park visitor may pick up a piece of fossilized bone during a hike along a park trail, believing that taking one fossil will not cause a problem. Multiplied by a million visitors per year, however, this activity can have a major impact on the resource. Poaching is also done by hobby collectors unaware of the legalities, as well as commercial collectors who specifically target areas within park units that are known to be fossil-rich and rarely patrolled (Benton et al. 2015).

In addition to the direct loss of fossils, fossil poaching also results in the loss of important contextual data. Even if a poached fossil is recovered, the geologic, taphonomic (what happens between the death of an organism and its discovery as a fossil), and paleoecological data that had been associated with the fossil before it was illegally removed can never be recovered (Beat and Hanna 2009).

The Paleontological Resources Preservation Act (2009) provides the National Park Service with mandates for protection of Federal fossil resources, and it clarifies the criminal penalties for fossil poaching (Benton et al 2015). Even with strengthened laws, however, fossil poaching and vandalism are still major issues for paleontological resources. From 2004 to 2014 nearly 900 individual law enforcement reports of fossil vandalism or poaching were documented in National Park System units (Santucci 2014).

One difficulty in prosecuting fossil poachers is the fact that unless they are "caught in the act," it is difficult if not impossible to prove that a fossil has been poached. Recent work utilizing rare Earth element signatures in fossils, however, is showing promise as a method to demonstrate the provenance of fossils. This information can then potentially be used to prove the origin of a poached fossil (Cerruti et al. 2014).

Because fossils and their contextual data are non-renewable resources, any amount of poaching impacts the resource in a negative way. We therefore classified significant fossil poaching as any formal or informal reports of poaching.

If fossil poaching occurrences were known, we assigned the condition *Warrants Significant Concern*. Because there is no amount of fossil poaching that is acceptable, we did not include a condition of *Warrants Moderate Concern* in our assessment. We gave the highest level of condition, *Resource in Good Condition,* if there was no fossil poaching known (Table 4.7.2).

Table 4.7.2. Paleontological resources condition categories for fossil poaching occurrences.

Resource condition		
Condition Icon Definition	**Condition Icon**	**Fossil poaching status**
Warrants significant concern		Fossil poaching occurrences are known
Warrants moderate concern		–
Resource in good condition		No fossil poaching occurrences are known

Data Sources

Some of the information summarized here was presented in a Geologic Resources Inventory Report prepared for the National Park Service (Graham 2009a). Other sources of information include scientific papers and books that we identify throughout this assessment. Especially useful was a recently published book on the White River Badlands geology and paleontology (Benton et al. 2015). No fieldwork was performed for this summary.

Quantifying Paleontological Condition, Confidence, and Trend

Indicator Condition

To quantify paleontological condition and trend, we used quantitative and qualitative data, expert opinion, and reports of prior impacts to the resource, as described above. For measurements beyond the scope of NPS guidelines, we created condition categories based on expert opinion and the scientific literature. We used a point system to assign each indicator to a category. This point system is based on the NPS methods that were developed to calculate overall air quality condition (NPS-ARD 2015), a methodical and rigorous assessment approach that can be applied to other resources as well. In this approach, we assigned zero points to the condition *Warrants Significant Concern*, 50 points to *Warrants Moderate Concern*, and 100 points to *Resource in Good Condition*. The average of all measures determined the condition category of the indicator; scores from 0–33 fell in the *Warrants Significant Concern* category, scores from 34–66 were in the *Warrants Moderate Concern* category, and scores from 67–100 indicated *Resource in Good Condition*.

Indicator Confidence

Confidence ratings were based on availability and type of data collected about the indicator. We gave a rating of *High* confidence when quantitative data were collected on site or nearby under similar conditions or in similar strata, quantitative data were collected recently, and quantitative data were collected methodically. We assigned a *Medium* confidence rating when quantitative data were not collected nearby, quantitative data were not collected recently, quantitative data collection was not repeatable or methodical, or data were qualitative only. *Low* confidence ratings were assigned when there were no good data sources to support the condition.

Indicator Trend

Potential trend categories were *Improving*, *Unchanging*, *or Deteriorating*. Because of the long timescales that are involved in many geologic processes as well as the complex interactions between geology and other natural processes such as precipitation, it is often difficult or impossible to see true trends in the condition of a geologic resource. To calculate a trend estimate for indicators, we sought quantitative or qualitative data that were collected at least sporadically for as long as the park unit has formally existed; in the case of Agate Fossil Beds NM this time period is 77 years (Graham 2009a). If there were no data available that met these monitoring requirements for a particular indicator, we indicated that trend was *Not Available* for that indicator.

Overall Paleontological Condition, Confidence, and Trend

We used the general approach for combining indicator conditions, trends, and confidence described in Chapter 3 (Methods 3.2.2) to calculate overall resource condition, trend, and confidence (Table 4.7.3).

Table 4.7.3. Summary of paleontological resources indicators and measures.

Indicator	Measure	Condition	Confidence	Trend	Condition rationale
Fossil loss	Amount of weathering and erosion	Not available	Low	Not available	Measured rates of weathering and erosion in Badlands NP are high and can expose fossils from bedrock and cause serious damage in a relatively short amount of time. No similar data exists for Agate Fossil Beds NM, so the condition for weathering and erosion that can impact fossil resources is *Not Available.*
	Fossil poaching and vandalism	Not available	Low	Not available	Reports of fossil poaching and vandalism in Badlands NP are somewhat common. No similar data exists for Agate Fossil Beds NM, so the condition for fossil poaching and vandalism is Not Available.

4.7.4. Paleontological Conditions, Confidence, and Trends

<u>Fossil Loss</u>

Condition: Not Available
Confidence: Low
Trend: Not Available

Condition

Because fossils are non-renewable resources, any factor that impacts is important to the assessment of the resource condition. We used two measures of fossil loss to assess its condition: 1) the amount of weathering and erosion occurring to the surface and thus potentially impacting fossils, and 2) the known occurrence of fossil theft within the park unit.

In both Badlands NP and Scotts Bluff NM, measureable rates of weathering and erosion for exposed bedrock come from metal survey markers that were emplaced flush with the bedrock surface and are now exposed. Although we can use these estimates for the amount of weathering and erosion that has historically impacted the strata at Agate Fossil Beds NM, no such markers exist in Agate Fossil Beds NM, nor are we aware of any other data source that reports current rates of weathering and erosion in the park. As a result, we had no method to identify if weathering and erosion are occurring at a rate that would result in damage to fossil resources. The condition for the amount of weathering and erosion was *Not Available*.

Fossil poaching and vandalism occurrence was the second measure used to assess the condition of fossil loss. In Badlands NP between 2011 and 2014, 1 to 3 formal cases per year of fossil poaching were prosecuted (Benton et al. 2015). Many more fossils were undoubtedly removed illegally, and paleontological inventories of National Grasslands in Nebraska and South Dakota have shown that more than a quarter of almost 300 fossil localities in those areas showed signs of poaching (Miller, 2003).

At Agate Fossil Beds National Monument, data for the amount of fossil poaching and vandalism are not available. As a result, we had no reference criteria to determine whether fossil poaching and vandalism is having any impact on fossil resources. While it is possible that poaching and vandalism do not occur at Agate Fossil Beds NM because the two main trails encourage visitors to stay on these trails and away from fossil sites other than the historic sites on the Fossil Hills, poaching and vandalism likely do happen. Without either quantitative or qualitative data, however, we are unable to assess the condition of this measure. Thus, condition for the measure of fossil poaching and vandalism occurrences was *Not Available*.

The average of both measures determined the condition category of the indicator; as the condition for both measures was Not Available, the condition for the indicator of fossil loss was *Not Available*.

Confidence

There were no quantitative data available on the rates of weathering and erosion of the surface at Agate Fossil Beds NM, and therefore we gave this measure a confidence rating of *Low*.

There was also no quantitative data available on fossil poaching and vandalism occurrences at Agate Fossil Beds NM, and therefore we gave this measure a confidence rating of *Low.*

Trend

Trend was *Not Available* for either measure, so trend was *Not Available* for the indicator of weathering and erosion.

<u>Paleontological Resource Overall Condition</u>

Condition

The overall paleontological resources condition was determined by the condition of the single indicator, fossil loss (Table 4.7.4). Fossil loss was given a condition of *Not Available*, which placed the overall paleontological resource condition for Agate Fossil Beds National Monument in the category *Not Available.*

Confidence

Confidence was *Low* for the single indicator of fossil loss, so overall confidence was *Low* for paleontological resources.

Trend

Trend data were *Not Available* for the single indicator of fossil loss, so overall trend for paleontological resources was *Not Available*.

Table 4.7.4. Paleontological resources overall condition.

Indicators	Measures	Condition
Fossil loss	• Amount of weathering and erosion • Fossil poaching and vandalism	

4.7.5. Stressors

We identified one potential stressor to paleontological resources: the timing and amounts of precipitation events. As demonstrated by the 2014 study that looked at the effects of weathering and erosion on fossil-bearing strata, single heavy precipitation events can have a large impact on short-term weathering and erosion (Stetler 2014). It has been predicted that climate change may result in an increase in the numbers of these extreme precipitation events for Badlands NP, and this assessment can likely be extended to nearby Agate Fossil Beds NM. An increase in these extreme precipitation events would in turn increase the impact of weathering and erosion on fossil resources (Amberg et al. 2012).

4.7.6. Data Gaps

We identified two data gaps for paleontological resources. The lack of data on rates of weathering and erosion at Agate Fossil Beds NM is a major gap, as this information would allow better assessment of the vulnerability of fossils to degradation by weathering and erosion. The Geological Resources Inventory report mentions that one specific locality, the carnivore den site on Beardog Hill, is the most threatened by weathering and erosion, but no data on the rates of weathering at that site or any others exists (Graham 2009). A study similar to one that was started at Badlands NP in 2010 (Stetler et al. 2014) that looked at the rates of weathering and erosion on fossil-bearing strata would yield very useful data on this topic.

A second data gap is the lack of information on fossil poaching and vandalism. The GRI report for Agate Fossil Beds NM (Graham 2009) also mentions that the carnivore den site on Beardog Hill is the most threatened by occasional vandalism, but no specific reports of this vandalism exist. The report also states that visitors often will pile loose fragments of fossil bone found near the historic quarries on the Fossil Hills into cairns, and that visitors may easily remove bone fragments as the quarries are not monitored. Even so, “there is no documentation that such fossil theft occurs at the park” (Graham 2009a). Such documentation would be useful in determining the true threat to fossil resources from poaching and vandalism at Agate Fossil Beds NM.

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4.8. Vegetation

The majority of the text in this chapter was written by Isabel W. Ashton and Christopher J. Davis for the 2011–2015 Summary Report, *Plant Community Composition and Structure Monitoring for Agate Fossil Beds National Monument*. The authors of the Agate Fossil Beds NM NRCA have reorganized several subsections of the Ashton and Davis (2016) report to follow the structure used for the other natural resource sections in this assessment. For this section, the Vegetation condition assessment, the term "we" refers to Ashton, Davis, and their team. Text included by the NRCA authors is denoted by italicized text in the Indicators and Measures section of 4.8.2 Methods.

4.8.1. Background and Importance

During the last century, much of the prairie within the Northern Great Plains has been plowed for cropland, planted with non-natives to maximize livestock production, or otherwise developed, making it one of the most threatened ecosystems in the United States. Within Nebraska, greater than 77% of the area of native mixed grass prairie has been lost since European settlement (Samson and Knopf 1994). The National Park Service (NPS) plays an important role in preserving and restoring some of the last pieces of intact prairies within its boundaries. The stewardship goal of the NPS is to "preserve ecological integrity and cultural and historical authenticity" (NPS 2012); however, resource managers struggle with the grim reality that there have been fundamental changes in the disturbance regimes, such as climate, fire, and grazing by large, native herbivores, that have historically maintained prairies and there is the continual pressure of exotic invasive species. Long-term monitoring in national parks is essential to sound management of prairie landscapes because it can provide information on environmental quality and condition, benchmarks of ecological integrity, and early warning of declines in ecosystem health.

Agate Fossil Beds National Monument (AGFO) was established in 1965 to protect and preserve a large concentration of ancient mammal fossils. The monument contains 2,270 acres of native mixed-grass prairie intersected by riparian vegetation along the Niobrara River. Vegetation monitoring began in AGFO in 1998 by the Heartland Inventory & Monitoring Program (James 2010a) and the Northern Great Plains Fire Ecology Program (FireEP; Wienk et al. 2011). In 2010, AGFO was incorporated into the Northern Great Plains Inventory & Monitoring Network (NGPN). At this time, vegetation monitoring protocols and plot locations were shifted to better represent the entire monument and to coordinate efforts with the FireEP (Symstad et al. 2012b), and sampling efforts began in 2011(Ashton et al. 2011). In 2012, the NGPN began monitoring an additional 17 plots within the riparian corridor to assess riparian condition. In this report, we use the data from 2011–2015 to assess the current condition of AGFO vegetation and the data from 1998–2015 are used to look at longer-term trends.

Using 18 years of plant community monitoring data in AGFO, we explore the following questions:

- What is the current status of plant community composition and structure of AGFO grasslands (species richness, exotic plant cover, and diversity) and how has this changed from 1998–2015?
- How do trends in grassland condition correlate with climate and fire history?
- What, if any, rare plants were found in AGFO long-term monitoring plots?

- How did installation of the AGFO Fossil Hills Trail affect the adjacent prairie?
- What is the composition and structure of the riparian corridor at AGFO?

4.8.2. Methods

Three different methods and protocols have been used to monitor long-term vegetation plots at AGFO since 1997: the NGPN monitoring protocol (Symstad et al. 2012b, a), the Fire Monitoring Handbook (NPS 2003), and the Heartland Vegetation Monitoring Protocol (James et al. 2009). Below we briefly describe all three methods, but focus on the NGPN monitoring protocol, which is the current standard and was used to collect most of the data in this report. For more detail on any of the methods, please see the protocol publications (cited above).

<u>NGPN and NGPFire Monitoring Plots 2011–2015</u>

The NGPN and NGPFire implemented a survey to monitor plant community structure and composition in AGFO using a spatially balanced probability design (Generalized Random Tessellation Stratified [GRTS]; Stevens and Olsen 2003, 2004). Using a GRTS design, NGPN selected 16 randomly located sites within the upland grasslands of AGFO to become Plant Community Monitoring plots (PCM plots; Figure 4.8.1). The NGPN visits 6 PCM plots every year using a rotating sampling scheme where three sites were visited in the previous year and three sites are new visits. After five years (2011–2015), most of the PCM plots were visited at least twice during the first weeks of June. When a PCM plot fell within an active burn unit, NGPFire added additional visits based on a 1, 2, 5, and 10 year sampling schedule. NGPFire also established and monitored a number of new sites focused in active burn units (Fire FPCM plots) using the same GRTS sampling schema. From 2011–2015, 16 FPCM plots were established. Finally, using the same set of random sites, NGPN selected 17 additional plots that fell within the riparian zone along the Niobrara River. These were monitored in 2012–2015 to assess the condition of riparian condition.

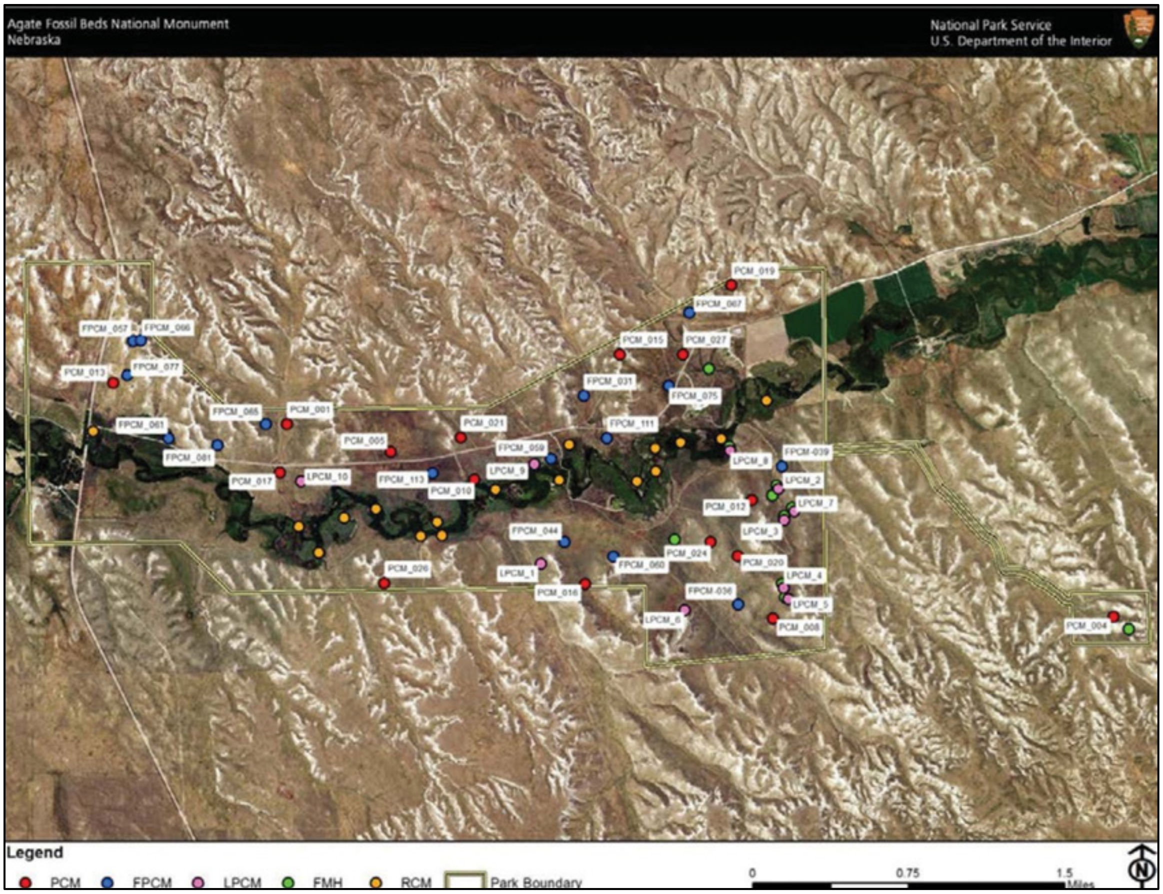

Figure 4.8.1. Map of Agate Fossil Beds National Monument (AGFO) plant community monitoring plots, 1997–2015. Sixteen PCM plots (red) were established by the Northern Great Plains Inventory & Monitoring Program (NGPN) and 16 (blue) FPCM plots were established by the Fire Effects Program (NGPFire) between 2011 and 2015. Ten LPCM plots were established by the Heartland Monitoring Network (pink) representing restored and native mixed-grass prairie. Seventeen plots were visited by the NGPN to monitor riparian forest condition (yellow). A few additional FMH plots (green) were monitored from 1997–2011 by NGPFire. There are a total of 64 monitoring plots (NPS) (figure from Ashton and Davis 2016).

At each of the grassland sites we visited, we recorded plant species cover and frequency in a rectangular, 50 meter x 20 meter (0.1 hectare), permanent plot (Figure 4.8.2). Data on ground cover and herb-layer (≤ 2 meter) height and plant cover were collected on two 50 meter transects (the long sides of the plot) using a point-intercept method (Figure 4.8.3). At 100 locations along the transects (every 0.5 meter) a pole was dropped to the ground and all species that touched the pole were recorded, along with ground cover, and the height of the canopy (Figure 4.8.3). Using this method, absolute canopy cover can be greater than 100% (particularly in wet years and productive sites) because we record multiple layers of plants. Species richness data from the point-intercept method were supplemented in the 16 PCM plots with species presence data collected in five sets of nested square quadrats (0.01 meter^2, 0.1 meter^2, 1 meter^2, and 10 meter^2) located systematically along each transect (Figure 4.8.2).

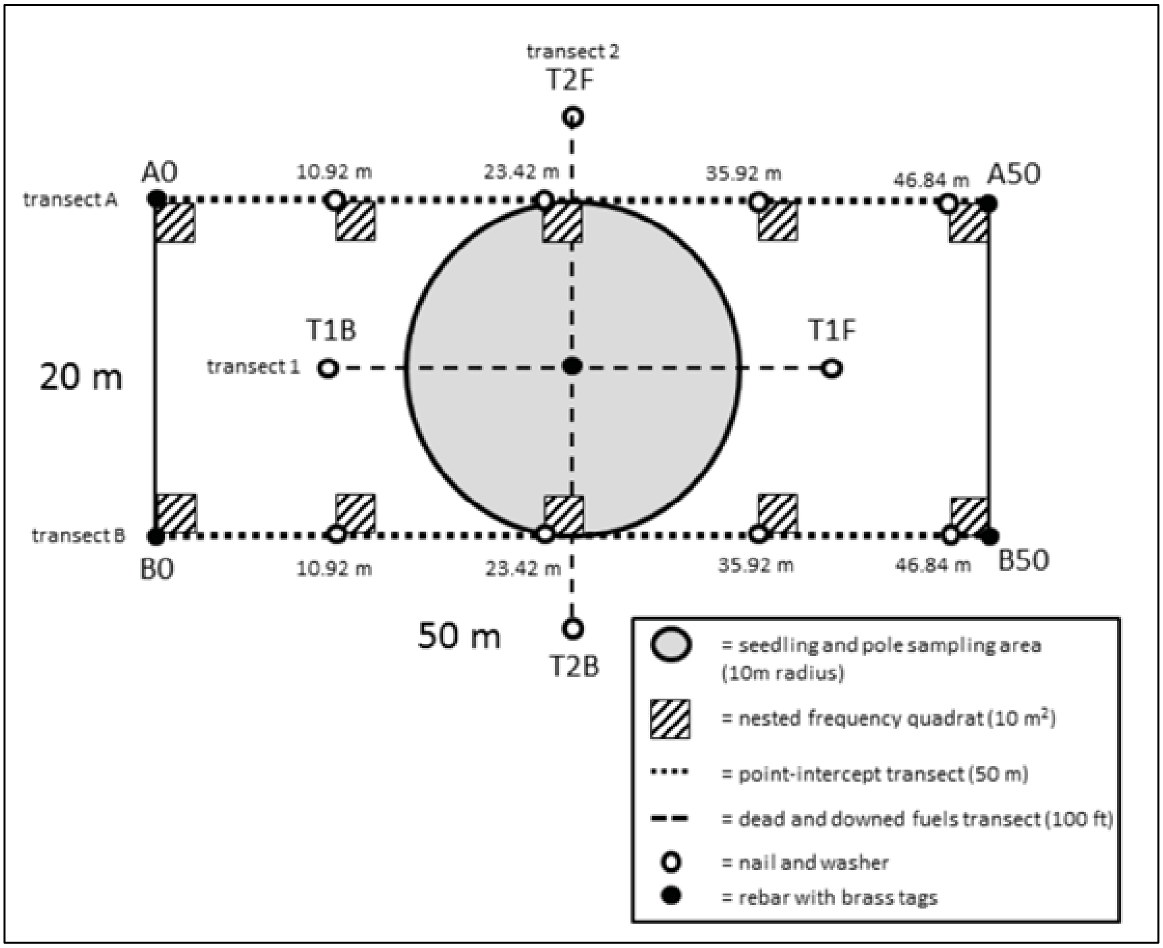

Figure 4.8.2. Long-term monitoring plot layout used for sampling vegetation in Agate Fossil Beds National Monument (Ashton and Davis 2016).

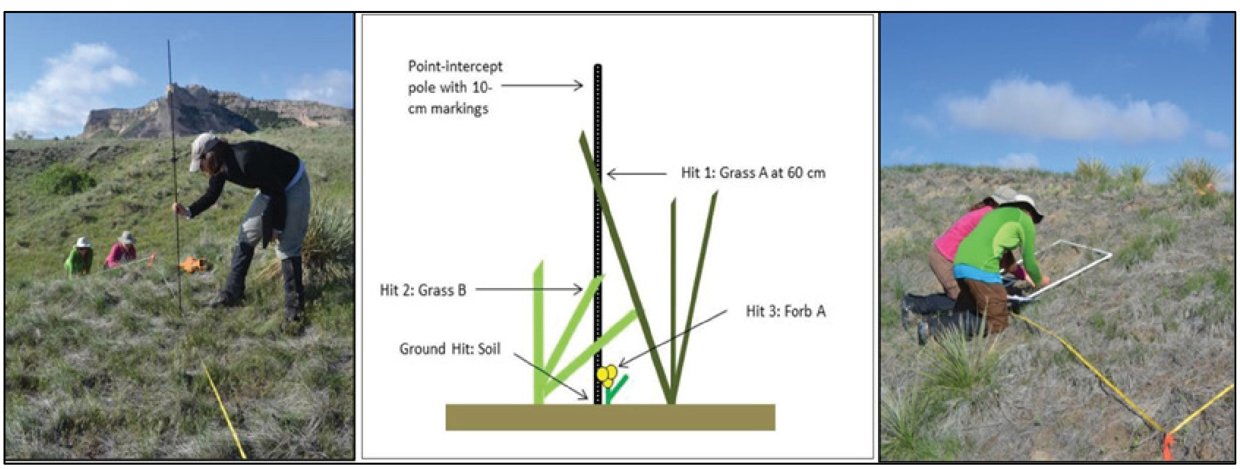

Figure 4.8.3. The Northern Great Plains Inventory & Monitoring vegetation crew used point-intercept (left and center panel) and quadrats (right panel) to document plant diversity and abundance.

NGPN completed a survey of the riparian zone in AGFO in August of 2012–2015 using a set of 17 randomly located sites. In this case, vegetation was measured using the point-intercept method, as described above, but it was measured along only one 50 meter transect that ran perpendicular to the river channel. These plots were not permanently marked and were relocated using GPS coordinates.

At all PCM plots, but not the FPCM plots, we also surveyed the area for common disturbances and target species of interest to AGFO. Common disturbances can include such things as rodent mounds, improvised and animal trails, and fire. For all plots, the type and severity of the disturbances were recorded. We also surveyed the area for exotic species that have the potential to spread into the monument and cause significant ecological impacts (Table 4.8.1). These species were chosen in collaboration with the Midwest Invasive Plant Network, the Exotic Plant Management Team, resource managers, and local weed experts. For each target species that was present at a site, an abundance class was given on a scale from 1–5 where 1 = one individual, 2 = few individuals, 3 = cover of 1–5%, 4 = cover of 5–25%, and 5 = cover > 25% of the plot. The information gathered from this procedure is critical for early detection and rapid response to such threats.

Table 4.8.1. Exotic species surveyed for at Agate Fossil Beds National Monument as part of the early detection and rapid response program within the Northern Great Plains Network.

Species name	Common name	Habitat
Alliaria petiolate	Garlic mustard	Riparian
Polygonum cuspidatum; P. sachalinense; P. x bohemicum	Knotweeds	Riparian
Pueraria montana var. *lobate*	Kudzu	Riparian
Iris pseudacorus	Yellow iris	Riparian
Ailanthus altissima	Tree of heaven	Riparian
Lepidium latifolium	Perennial pepperweed	Riparian
Arundo donax	Giant reed	Riparian
Rhamnus cathartica	Common buckthorn	Riparian
Heracleum mantegazzianum	Giant hogweed	Riparian
Centaurea solstitalis	Yellow star thistle	Upland
Hieracium aurantiacum; H. caespitosum	Orange and meadow hawkweed	Upland
Isatis tinctoria	Dyer's woad	Upland
Taeniatherum caput-medusae	Medusahead	Upland
Chondrilla juncea	Rush skeletonweed	Upland
Gypsophila paniculata	Baby's breath	Upland
Centaurea virgate; C. diffusa	Knapweeds	Upland
Linaria dalmatica; L. vulgaris	Toadflax	Upland
Euphorbia myrsinites; E. cyparissias	Myrtle spurge	Upland
Dipsacus fullonum; D. laciniatus	Common teasel	Upland
Salvia aethiopis	Mediterranean sage	Upland
Ventenata dubia	African wiregrass	Upland

Other Monitoring Plots (1997–2015)

In 1997, NGPFire began monitoring plots within AGFO to evaluate the effectiveness of prescribed burns. Starting in 1998, data collection followed the NPS National Fire Ecology Program protocols (NPS 2003): in grassland plots vegetation cover and height data were collected using a point-intercept method, with 100 points evenly distributed along a single 30 meter transect. NGPFire plot locations were located randomly within major vegetation types within areas planned for prescribed burning (burn units) in the near future. The plots were then sampled 1, 2, 5, and 10 years after a prescribed burn. The data were not collected using these protocols in 2010, so this year was excluded from analyses. Hereafter, we refer to these plots as Fire Monitoring Handbook (FMH) plots. These FMH plots are being retired after the 10 year visit (e.g. the rebar will be removed) and replaced with the FPCM plots described above.

The Heartland Inventory & Monitoring Program also established a number of plots in 1997. Plant frequency was measured using circular subplots as described in the Heartland Networks' vegetation monitoring protocol (James et al. 2009). The data and a summary of results from these plots are described in detail by James (2010b). In 2009, 2013 and 2014, a subset of these plots (called Legacy Plant Community Monitoring Plots, LPCMs) was revisited by NGPN and point-intercept data was also collected using the methods described above. In this report, we present the point-intercept from the three survey years, but do not report frequency. These plots were chosen to revisit because they were established to evaluate the disturbance caused by a trail installation. Three plots were established adjacent to the trail in areas of prairie impacted by construction disturbance (LPCM_2, 3 and 7)and two plots were established nearby in undisturbed native prairie (LPCM_4 and 5).

Indicators and Measures

Summaries of indicators came directly from Ashton and Davis (2016) unless italicized; text in italics was added by NRCA authors.

Indicator: Upland Plant Community Structure and Composition

The vegetation structure and composition of the Northern Great Plains have changed since Agate Fossil Beds NM was first established. While much prairie within the boundary of the park unit is still intact, many of the natural processes that helped shape the landscape, such as grazing by bison, are now gone (Ricketts et al. 1999). Understanding the composition and structure of upland species within park will help with efforts to protect the native prairie that is still present.

Measure of Upland Plant Community Structure and Composition: Native Species Richness

Species richness is simply a count of the species recorded in an area. Plant richness was calculated for each plot using the total number of species intersected along the transects.

Measure of Upland Plant Community Structure and Composition: Evenness

Peilou's Index of Evenness, J', measures how even abundances are across taxa. It ranges between 0 and 1; values near 0 indicate dominance by a single species and values near 1 indicate nearly equal abundance of all species present.

Evenness is a diversity index that describes the similarity in number of members that belong to different groups in a community. Values for evenness may fall between 0 and 1. If all groups have a similar number of members, the community is very even, with an evenness value close to 1. Communities that have high evenness can remain more functional in environmentally stressful conditions than uneven communities (Wittebolle et al. 2009).

Indicator: Exotic Plant Early Detection and Management

A major threat to native plant communities is the spread of exotic (non-native) plants (McKinney and Lockwood 1999). Environmental conditions can affect how well natives compete with invasive species (Nernberg and Dale 1997), as can the local and regional abundance of particular invasive species (Carboni et al. 2016). Additionally, the characteristics of the existing native plant community can determine how likely it is to be invaded (Thuiller et al. 2010). Identifying and managing the exotic species that are present at Agate Fossil Beds NM is important for protecting the native prairie within in the park.

Measure of Upland Plant Community Structure and Composition: Relative Cover of Exotic Species

Relative cover of exotic species is the proportion or percentage of a surveyed area that is made up of exotic species. Calculating the absolute cover of a plant species (all of the area covered by a species) is both impractical and unnecessary, but researchers can calculate the proportion of the park that is covered by a species by sampling plots and transects that area representative of the ecosystems within the park.

Measure of Upland Plant Community Structure and Composition: Annual Brome Cover

Cheatgrass and Japanese brome are both Eurasian, annual grasses that have been a part of the NGP landscape for more than a century, but their invasion in the region has accelerated since 1950 (Schachner et al. 2008). The presence of annual bromes in mixed grass prairie is associated with decreased productivity and altered nutrient cycling (Ogle et al. 2003). There is strong evidence from regions further west that cheatgrass alters fire regimes and the persistence of native species (D'Antonio and Vitousek 2003).

Indicator: Upland Riparian Community Structure and Composition

Riparian zones exist where rivers or streams meet land. The vegetation in these areas may be particularly diverse (Naiman and Decamps 1997) and lush, and can be a striking difference from upland ecosystems in drier regions like the Northern Great Plains.

Riparian ecosystem community composition and structure are largely determined by the flow patterns of the streams that they border (Johnson 1998), where plants are subject to seasonal changes and annual variation in flow.

Measure of Upland Riparian Community Structure and Composition: Native Species Richness

See description above

Measure of Upland Riparian Community Structure and Composition: Relative Cover of Exotic Species

See description above

Measure of Upland Riparian Plant Community Structure and Composition: Relative Cover of Pale Yellow Iris

Pale yellow iris (*Iris pseudacorus*) is a Eurasian species that typically grows in temperate freshwater and brackish marsh communities (Sutherland 1990). Its showy flower has made it a favorite ornamental plant and it is now considered invasive across much of North America. Pale yellow iris has the potential to uplift sediments, alter habitat, reduce diversity of native species, and these changes favor its continued spread (Thomas 1980). It was first introduced in the Niobrara basin in 1906 upstream of AGFO in a manmade, spring fed pond on Agate Springs Ranch.

Data Management and Analysis

We used FFI (FEAT/FIREMON Integrated; http://frames.gov/ffi/) as the primary software environment for managing our sampling data. FFI is used by a variety of agencies (e.g., NPS, USDA Forest Service, U.S. Fish and Wildlife Service), has a national-level support system, and generally conforms to the Natural Resource Database Template standards established by the Inventory and Monitoring Program.

Species scientific names, codes, and common names are from the USDA Plants Database (USDA-NRCS 2015). However, nomenclature follows the Integrated Taxonomic Information System (ITIS) (http://www.itis.gov). In the few cases where ITIS recognizes a new name that was not in the USDA PLANTS database, the new name was used, and a unique plant code was assigned. This report uses common names after the first occurrence in the text, but scientific names can be found in Appendix A.

After data for the sites were entered, 100% of records were verified to the original data sheet to minimize transcription errors. A further 10% of records were reviewed a second time. After all data were entered and verified, automated queries were used to check for errors in the data. When errors were caught by the crew or the automated queries, changes were made to the original datasheets and/or the FFI database as needed. Summaries were produced using the FFI reporting and query tools and statistical summaries, and graphics were generated using R software (version 3.2.2).

Plant life forms (e.g., shrub, forb) were based on definitions from the USDA Plants Database (USDA-NRCS 2015). The conservation status ranks of plant species in Nebraska is determined by the Nebraska Natural Heritage Program (NENHP). For the purpose of this report, a species was considered rare if its conservation status rank was S1, S2, or S3. See Table 4.8.2 for a detailed definition of each conservation status rank.

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Table 4.8.2. Definitions of state and global species conservation status ranks. Adapted from NatureServe status assessment table (http://www.natureserve.org/conservation-tools/conservation-status-assessment).

Status rank	Category	Definition
S1/G1	Critically imperiled	Due to extreme rarity (5 or fewer occurrences) or other factor(s) making it especially vulnerable to extirpation
S2/G2	Imperiled	Due to rarity resulting from a very restricted range, very few populations (often 20 or fewer), steep declines, or other factors making it very vulnerable to extirpation
S3/G3	Vulnerable	Due to a restricted range, relatively few populations (often 80 or fewer), recent widespread declines, or other factors making it vulnerable to extirpation
S4/G4	Apparently secure	Uncommon but not rare; some cause for concern due to declines or other factors
S5/G5	Secure	Common, widespread and abundant
S#S#	Range rank	Used to indicate uncertainty about the status of the species or community
G#G#	(e.g. S2S3)	Ranges cannot skip for more than one rank

* S = state ranks, G = global ranks.

We measured diversity at the plots in two ways: species richness and Pielou's Index of Evenness. Species richness is simply a count of the species recorded in an area. Peilou's Index of Evenness, J', measures how even abundances are across taxa and ranges between zero and one; values near zero indicate dominance by a single species and values near one indicate nearly equal abundance of all species present. Plant richness was calculated for each plot using the total number of species intersected along the transects. Average height was calculated as the average height per plot using all species intersected on the transects.

Climate data from the Agate 3E, Nebraska weather station (GHCND: USC00250030) were downloaded from NOAA's online database (NOAA 2015). Fire history maps were compiled for AGFO and cross-referenced with plot locations. For each time data were collected at a plot (i.e., plot visit), we determined the number of years since the plot had burned and the number of fires recorded for that plot. For plots where no burns were recorded, we calculated the difference between the year of data collection and the oldest fire recorded in AGFO. This is likely an underestimate of the true time since it burned because fires were infrequent prior to the 1980s.

<u>Reporting on Natural Resource Condition</u>

Results were summarized in a Natural Resource Condition Table based on the templates from the State of the Park report series (http://www1.nrintra.nps.gov/im/stateoftheparks/index.cfm). The goal is to improve park priority setting and to synthesize and communicate complex park condition information to the public in a clear and simple way. By focusing on specific indicators, such as exotic species cover, it will also be possible and straightforward to revisit the metric in subsequent years.

We chose a set of indicators and specific measures (See section on Indicators and measures of vegetation condition) that can describe the condition of vegetation in the Northern Great Plains and the status of exotic plant invasions. The measures include: absolute herb-layer canopy cover, native species richness, evenness, relative cover of exotic species, and annual brome cover. Reference values were based on descriptions of historic condition and variation, past studies, and/or management targets. Current park unit condition was compared to a reference value, and status was scored as *Good Condition*, *Warrants Moderate Concern*, or *Warrants Significant Concern* based on this comparison. Good condition was applied to values that fell within the range of the reference value, and significant concern was applied to conditions that fell outside the bounds of the reference value. In some cases, reference conditions can be determined only after we have accumulated more years of data. When this is the case, we refer to these as "To be determined" and estimate condition based on our professional judgment.

Quantifying Overall Vegetation Quality Condition, Confidence, and Trend

The NRCA authors used the general approach for combining indicator conditions, trends, and confidence described in Chapter 3 (Methods 3.2.2) to calculate overall resource condition, trend, and confidence based on the results presented by Ashton and Davis.

4.8.3. Results and Discussion (In other NRCA sections: Vegetation Quality Conditions, Confidence, and Trends)

Status & Trends in Community Composition and Structure of AGFO Prairies

There are 453 plant species on the AGFO species list and we found 277 plant species in monitoring plots from 1998–2015 at AGFO (Appendix C). Graminoids, which includes grasses, sedges, and rushes, accounted for most of the vegetative cover at AGFO, but forbs, shrubs and subshrubs were also present (Figure 4.8.4). We found 47 exotic plant species at AGFO, all of which were forbs or graminoids. Exotic graminoids were particularly abundant (Figure 4.8.4). The shrubs and subshrubs were all native species.

Needle and thread (*Heterostipa comata*), prairie sand reed (*Calamovilfa longifolia*), Western wheatgrass (*Pascopyrum smithii*), and slender wheatgrass (*Elymus trachycaulus*) were the most abundant native grasses and averaged between 8 and 25% absolute cover (Figure 4.8.5). There were no exotic species in the 10 most common plants in AGFO (Figure 4.8.5). There is also no evidence that exotic cover has increased since 1998 ($F_{1, 52}=0.65$ $P=0.42$), but exotic species are still a concern. The cover of exotic species in 2011–2015 averaged 17.6 ± 2.5% (mean ± standard error) and it was 16.4 ± 2.5% for the entire period of record. Kentucky bluegrass (*Poa pratensis*), prickly Russian thistle (*Salsola tragus*), cheatgrass (*Bromus tectorum*) and Japanese brome (*B. japonicus*) were the most pervasive exotics at AGFO. We found no targeted early detection species (Table 4.8.1) in the upland areas of AGFO. Cheatgrass and Japanese brome are both Eurasian, annual grasses that have been a part of the NGP landscape for more than a century, but their invasion in the region has accelerated since 1950 (Schachner et al. 2008). The presence of annual bromes in mixed grass prairie is associated with decreased productivity and altered nutrient cycling (Ogle et al. 2003). There is strong evidence from regions further west hat cheatgrass alters fire regimes and the persistence of native species (D'Antonio and Vitousek 2003). From 1998 to 2015, the average relative cover of annual bromes was 5.8 ± 1.5% and the average for the last 5 years was 7.4 ± 1.9%. While the cover of annual bromes has not been increasing over time in AGFO ($R^2=0.19$, $F_{1, 52}=0.29$ $P=0.59$; Figure

4.8.6), there is evidence that annual bromes are increasing within other National Park units in the region (unpublished data).

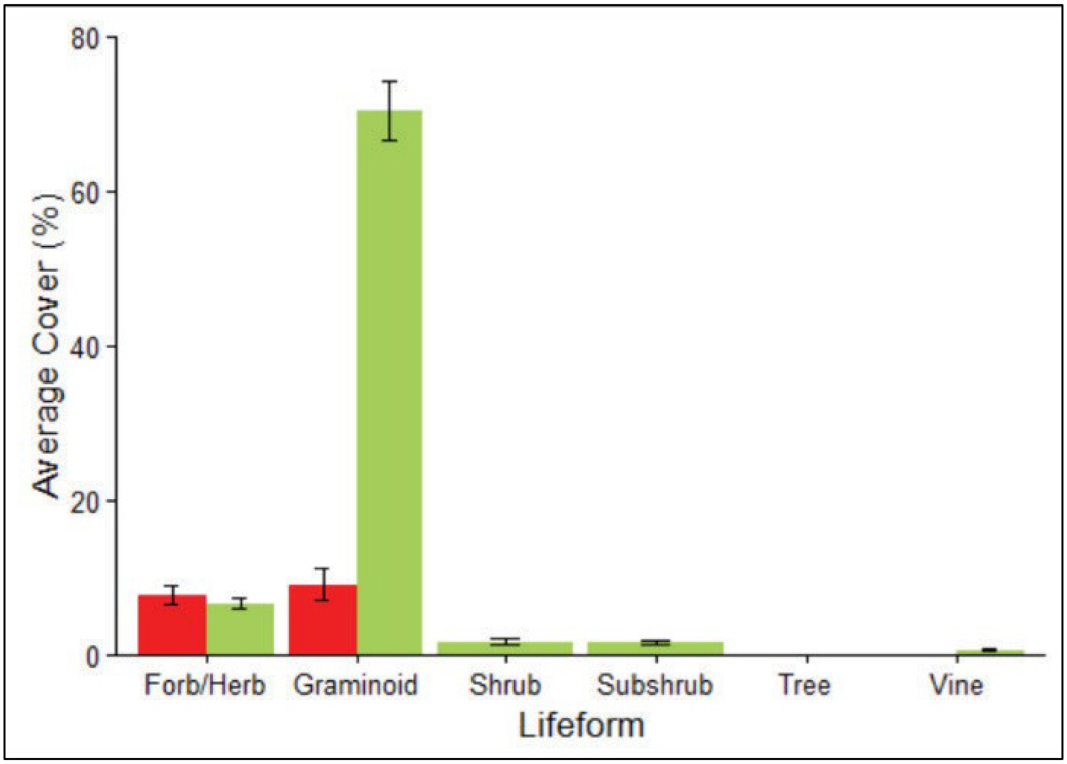


Figure 4.8.4. Average cover by lifeform of native (green) and exotic (red) plants recorded in monitoring plots in Agate Fossil Beds National Monument (1998–2015) (Ashton and Davis 2016). Absolute cover can be greater than 100% because the point-intercept methods records layers of overlapping vegetation.

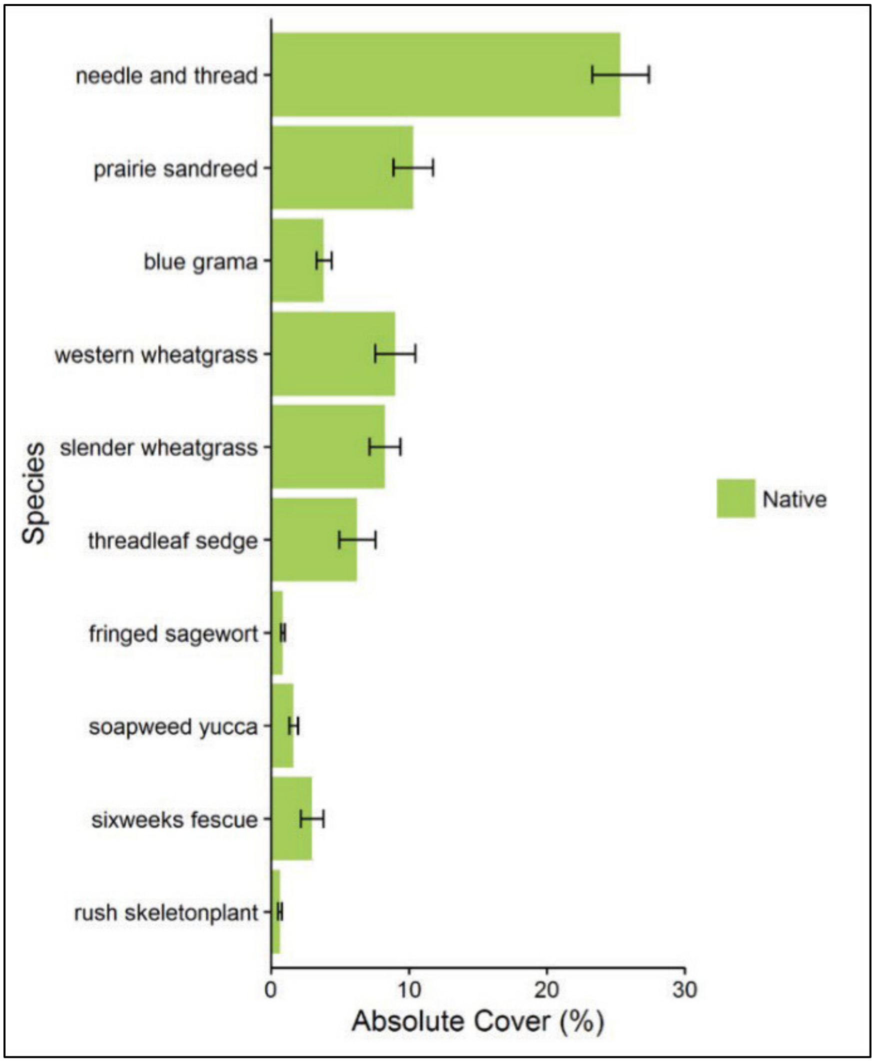


Figure 4.8.5. The average absolute cover of the 10 most common native plants recorded at Agate Fossil Beds National Monument in 1998–2015 (Ashton and Davis 2016). Bars represent means ± one standard error. All of the 10 most common plants were native species.

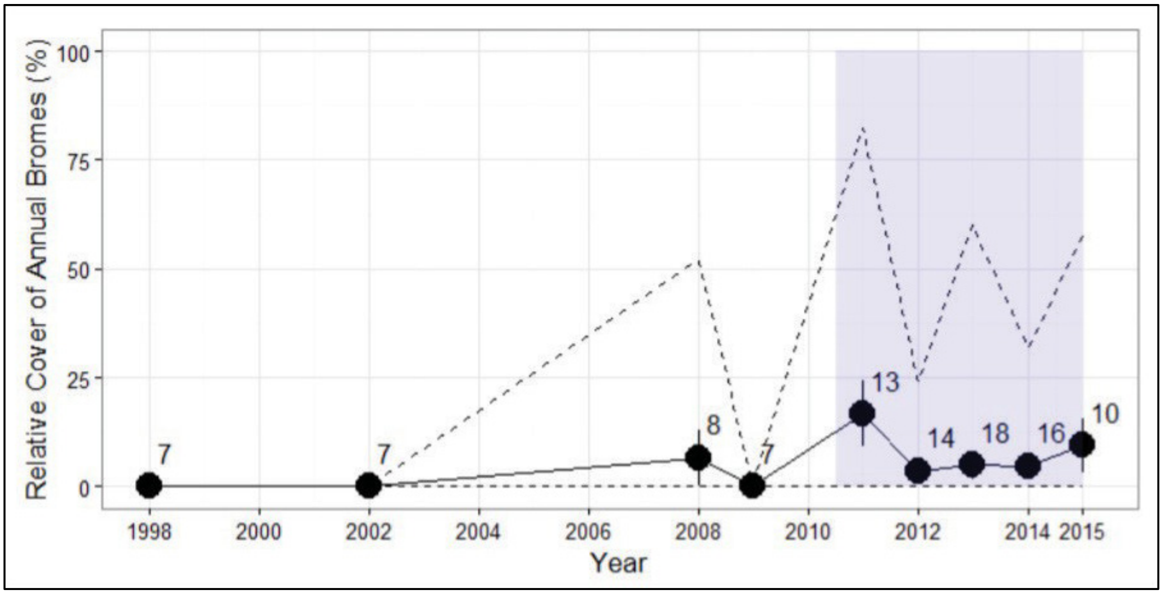


Figure 4.8.6. Trends in the relative cover of annual bromes in Agate Fossil Beds National Monument from 1998–2015 (Ashton and Davis 2016). Points represent mean ± one standard errors and sample size is to the right of the point. Years with fewer than three monitoring plots were excluded from the graph. The shaded area highlights the period from 2011–2015 when sampling methods were consistent and distribution of plots was more even and consistent across years. The dashed line represents the maximum and minimum cover values for each year.

Species Richness, Diversity, and Evenness

One of the ways for the NPS to measure effectiveness of actions to achieve its mission of "preserving ecological integrity" is to examine trends in native plant diversity and evenness within park unit boundaries. Average species richness has been measured by point-intercept since 1998 and in 1 meter^2 and 10 meter^2 quadrats since 2011 (Table 4.8.3).

Table 4.8.3. Average plant species richness in monitoring plots at Agate Fossil Beds National Monument from 1998 to 2015. Values represent means ± one standard error.

Richness category	Point-intercept (1998–2015; n=47)	1m^2 quadrats (2011–2015; n=31)	10m^2 quadrats (2011–2015; n=31)
Species richness	11.8 ± 0.6	8.7 ± 0.6	14.8 ± 0.9
Native species richness	9.8 ±0.6	7.3 ± 0.5	12.2 ± 0.8
Exotic species richness	2.8 ± 0.2	1.4 ± 0.2	2.5 ± 0.3
Graminoid species richness	6.0 ± 0.2	3.6 ± 0.2	4.7 ± 0.2
Forb species richness	5.0 ± 0.4	4.5 ± 0.4	8.9 ± 0.6

While there was some variation across the monument, the plots we visited in AGFO tended to have a moderate diversity of native plants compared to other mixed-grass prairies. Species richness in the mixed-grass prairie is determined by numerous factors including fire regime, grazing, disturbance, and weather fluctuations (Symstad and Jonas 2011). While it is difficult to define a reference condition for species richness, which naturally varies considerably across both space and time, the natural range of variation over long-time periods may be a good starting point (Symstad and Jonas 2014). Long-term records of species diversity in mixed-grass prairie from a relatively undisturbed site in Kansas varied between 3 and 15 species per square meter over the course of 30 years (Symstad and Jonas 2014). Compared to this, AGFO is within the natural range (7 species). Only one site, PCM_005 (Figure 4.8.1; middle) fell below this reference condition. This site is very close to the road and was likely impacted by construction. The most diverse plot, AGFO_ PCM_012 (Figure 4.8.1; southeast), averaged 10.2 species.

We did not find any directional change in species richness or evenness over time (Figure 4.8.7). Native species richness in 1 meter^2 quadrats was consistent from 2011 to 2015; it ranged from a low in 2012 of 4.5 ± 0.6 (a drought year) to a high of 9.5 ± 0.9 in 2014 (a wet year). In the longer record from point-intercept data (1998–2015; Figure 4.8.8: top) annual average native richness ranged between 7 and 14 species. Annual average evenness of native species ranged from 0.62 to 0.72 during this time period, indicating the plots were not strongly dominated by a single species (Figure 4.8.8: bottom). There is a great deal of variation in species richness and evenness among sites within AGFO (dashed lines in Figure 4.8.8 represent the maximum and minimum values) which makes long-term trends in these metrics difficult to detect.

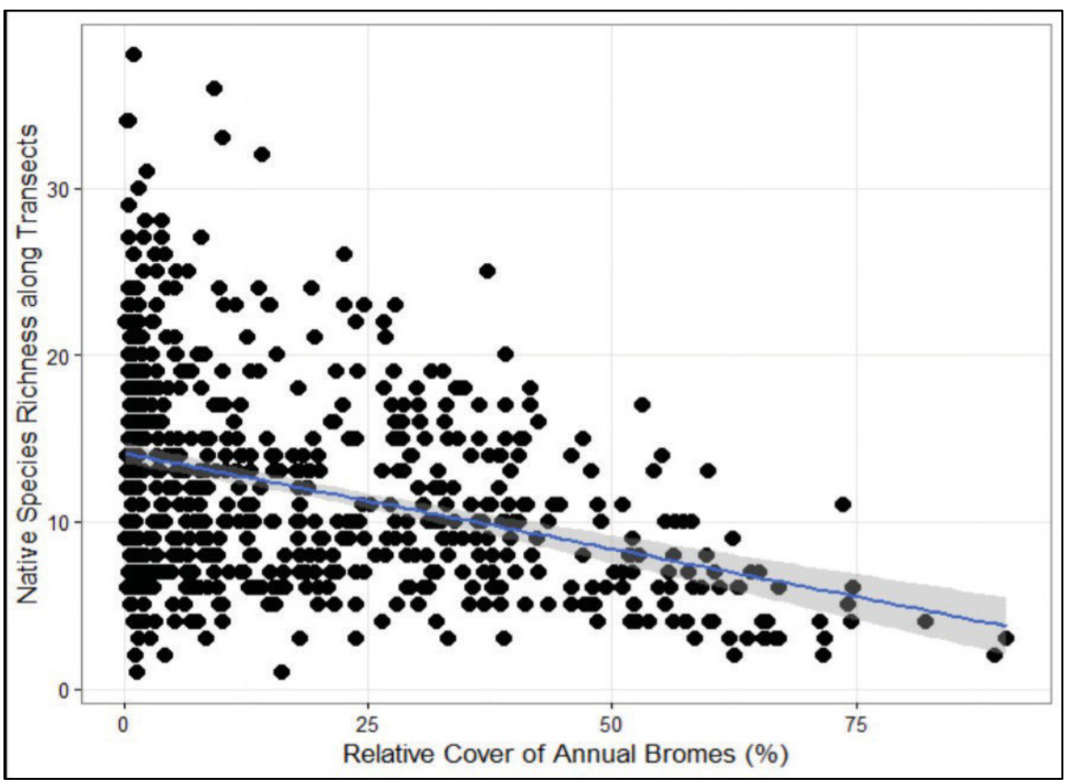


Figure 4.8.7. The relationship between native species richness and the relative cover of annual bromes in long-term monitoring plots in National Park units of the Northern Great Plains, 1998–2015 (Ashton and Davis 2016).

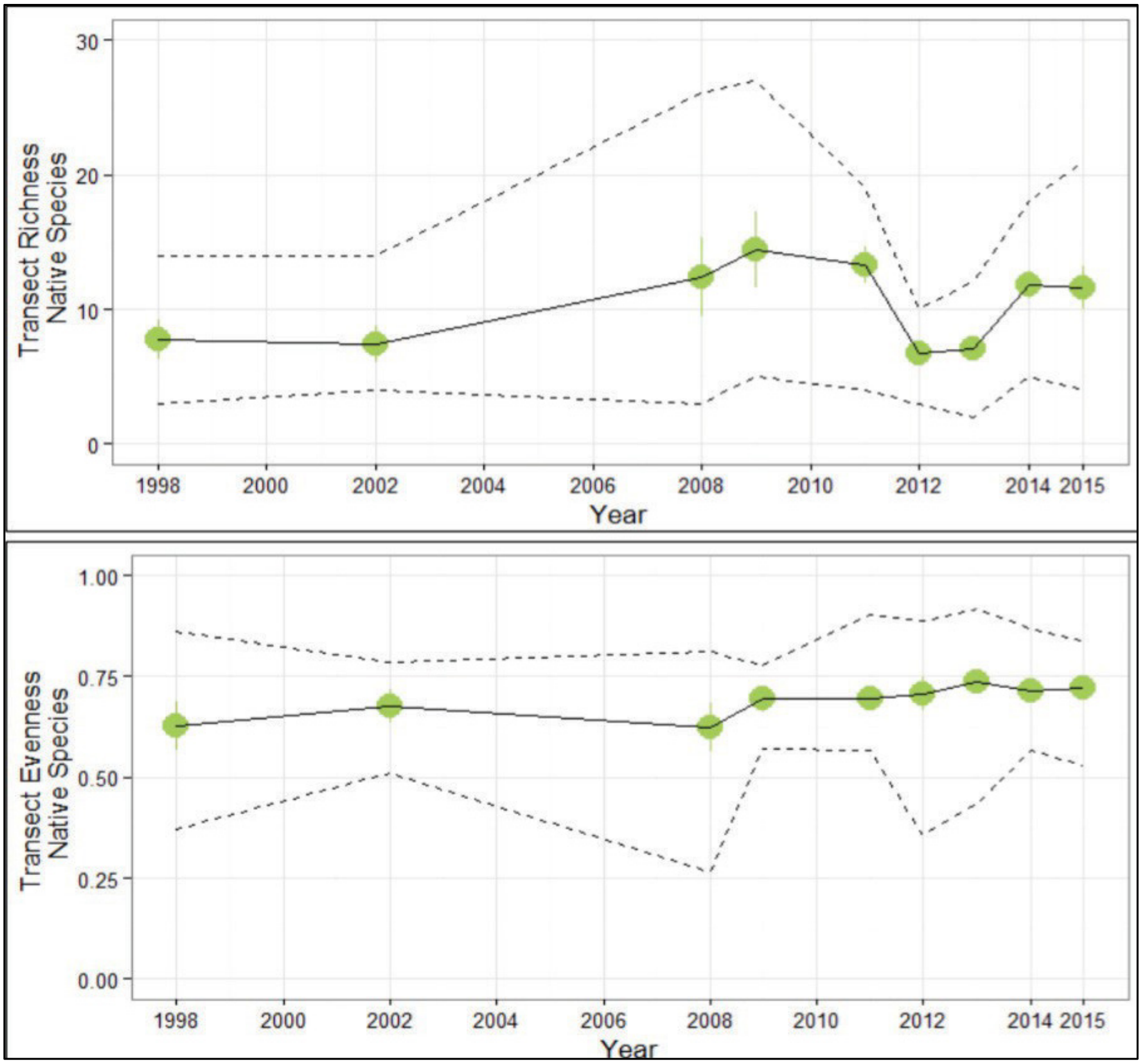


Figure 4.8.8. Trends in native species richness and evenness in Agate Fossil Beds National Monument, 1998–2015 (Ashton and Davis 2016). Data are means ± one standard error. The dashed line indicates the maximum and minimum values for each year.

There is evidence from other regions that annual bromes can affected persistence of native species (D'Antonio and Vitousek 2003). In AGFO and other nearby Northern Great Plains parks, there is a negative correlation between the cover of annual bromes and native species richness (F1, 551=36.5, P < 0.0001) (Figure 4.8.7). If the cover of annual bromes in AGFO increases over time, we expect there will be a corresponding decline in native species richness.

Disturbance from grazing, fire, and humans affects plant community structure and composition in mixed-grass prairie. We estimated the approximate area affected by natural and human disturbances at each site we visited in 2011–2015 by surveying the area for ~ 5 minutes at the end of the plot visit.

The most common disturbance was from rodents (e.g. pocket gophers) and it was widespread, occurring in 21 plots. There was also evidence of prescribed fires and off-road use, but this occurred in fewer plots (7 and 6 plots, respectively). We found no correlation with total disturbance, small or large animal disturbance and native richness or exotic cover. As more monitoring data are collected in future years, we may be able to better explore the statistical relationship between these metrics and disturbance.

The Influence of Climate and Fire on Plant Community Structure and Diversity

Climate

The Northern Great Plains has a continental climate, with hot summers and very cold winters. The 30-year normal temperatures at a nearby weather station, Agate 3E, Nebraska ranged from average minimum monthly temperatures in December of 7.8° F to maximum monthly July temperatures of 88.7° F (based on 1980–2010). The 30-year normal annual precipitation totals 14.37 inches. Annual precipitation at AGFO in 1998–2015 was variable and ranged between 4.5 and 21.3 inches, in 2012 and 2009, respectively. There were dry years in the early 2000s, 2006–2008, and in 2012 (Figure 4.8.9). The last two years have been much wetter than average. The native vegetation is adapted to this variation, and productivity responds strongly to decreases in spring and summer precipitation (Yang et al. 1998, Smart et al. 2007). Species richness and diversity in regional grasslands are also sensitive to temperature and precipitation fluctuation, but the response is complex and less predictable (Jonas et al. 2015).

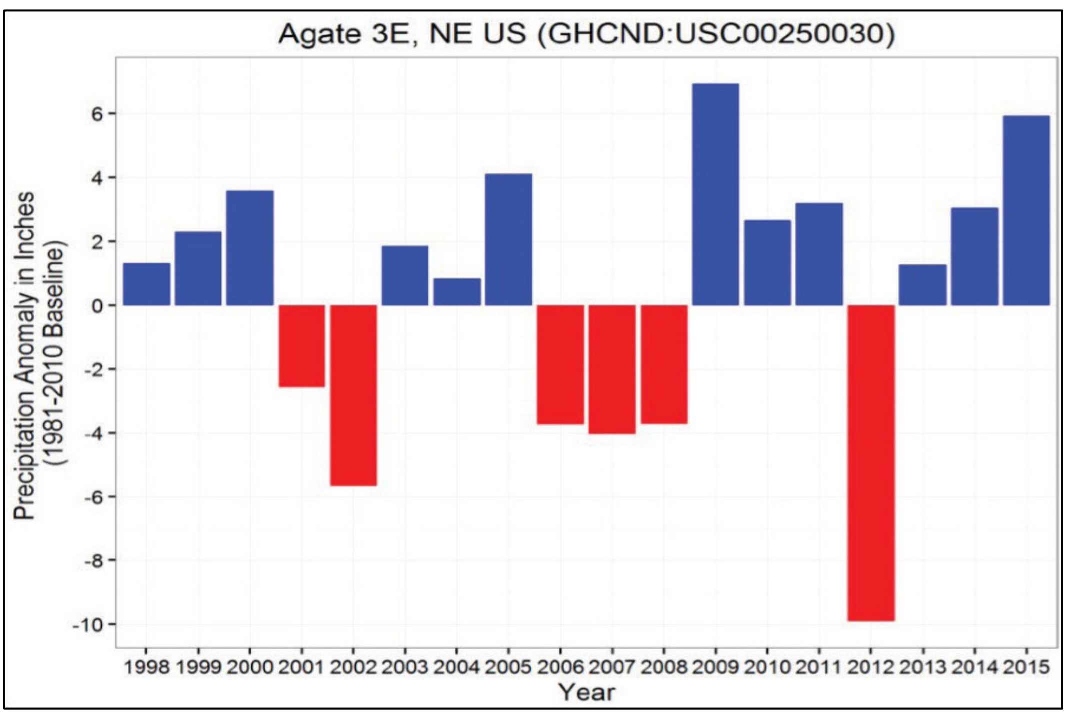


Figure 4.8.9. The total annual precipitation anomaly from 1998–2015 for Agate Fossil Beds National Monument (Asthon and Davis 2016). Positive values (blue) represent years wetter than and negative values (red) years drier than the 1981–2010 average. The anomaly is measured in inches and based on data from a nearby weather station.

We found that native species richness increased in response to increasing precipitation (F1, 52=11.1, P < 0.001). Plant height and exotic cover also responded to precipitation (F1, 52=4.2, P=0.047, F1, 52=6.2, P=0.016, for height and cover respectively) and maximum temperature (F1, 52=7.8, P=0.007, F1, 52=13.8, P < 0.001). However, the response was driven by 2012, an extremely hot and dry year (Figure 4.8.10). When 2012 was excluded from analysis neither height nor exotic cover showed a significant response to temperatures or precipitation. Similarly, native species richness declined in 2012 when average maximum temperatures were very hot, but otherwise there was no significant response over this time period. Continued monitoring and a longer time series of vegetation data and climate will allow us to determine whether the response to the 2012 drought is typical.

Figure 4.8.10. A long-term monitoring plot in Agate Fossil Beds National Monument in 2012, during a severe drought, and 2014 a wet year.

Historically, fire was a common disturbance in Northern Great Plains grasslands, with natural fire return intervals of 9–12 years (Guyette et al. 2015). Natural fires have been suppressed for most of the last century, but the use of prescribed burning in Northern Great Plains parks to mitigate the effects of the absence of natural fires has increased over time since its start at Wind Cave NP in 1973 (Wienk et al. 2011). As of 2015, there is a mosaic of recently burned and unburned areas at AGFO (Figure 4.8.11).

The effects of specific prescribed burns on vegetation and fuel loads and more details about fires at AGFO can be found in past NGPFire annual reports (see http://www.nps.gov/ngpfire/docs.htm). Here, we were interested in determining the relationship between fire history and vegetation. We compared two vegetation metrics, native species richness and relative cover of exotic plants, with the length of time between the data collection at a plot and the most recent fire at that plot (years since fire). For example, a site that burned in the spring and then was visited in the summer would be 0 years since fire. We excluded plots that had not burned from this analysis, because we do not have confidence in the historical fire record (pre-1980s).

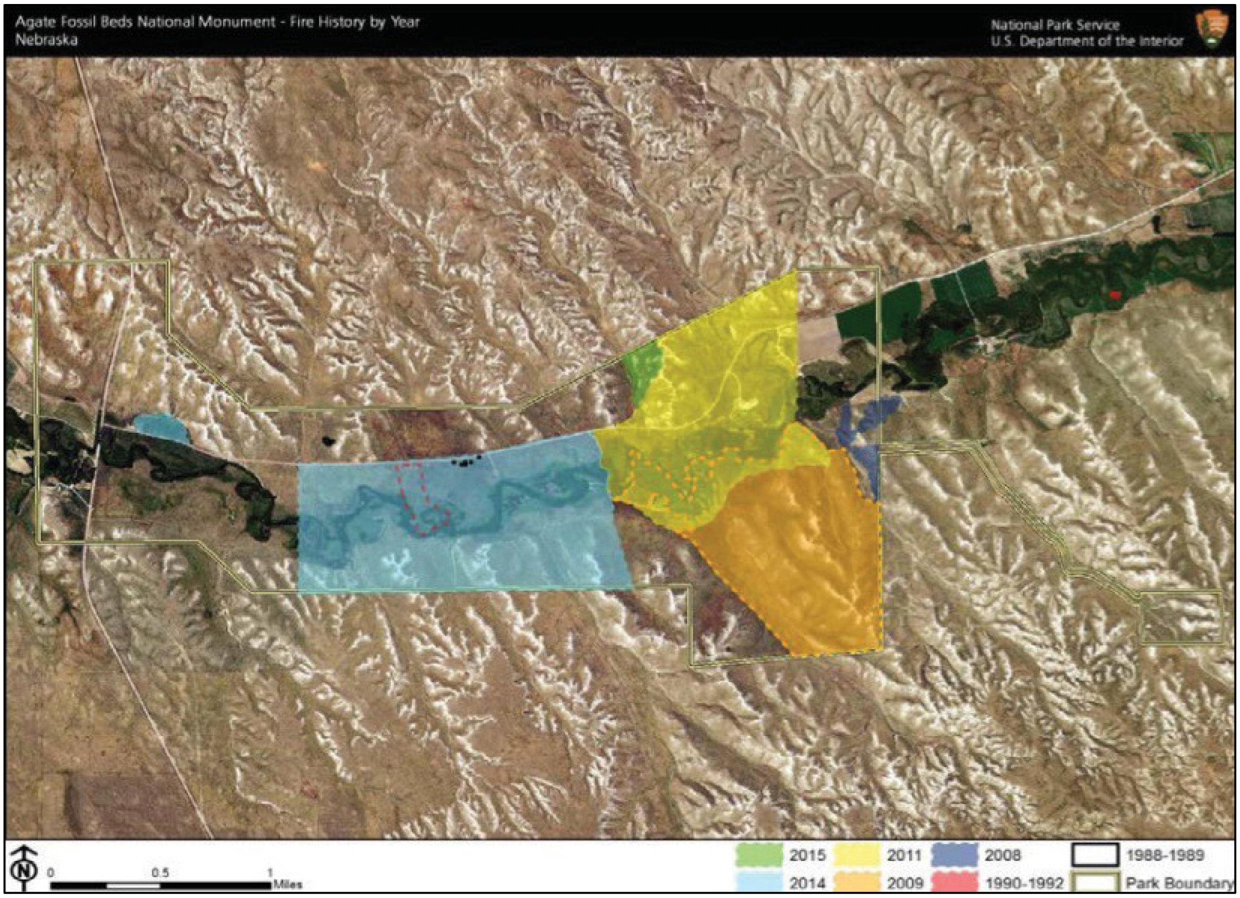


Figure 4.8.11. Map of recent fire history at Agate Fossil Beds National Monument (NPS) (Ashton and Davis 2016).

We found a strong positive relationship between native richness and years since fire ($F_{1, 32}=32.6$, $P < 0.0001$) (Figure 4.8.12). Exotic species cover declined significantly as years since fire increased ($F_{1, 32}=4.8$, $P=0.036$) (Figure 4.8.12). Annual bromes show a similar pattern, but it is not significant. Plots that had not burned in 5 or 6 years had a higher number of native species and a lower cover of exotics than sites that burned more recently and when compared to AGFO averages. This suggests that prescribed fire can benefit the mixed-grass prairie in AGFO, but it may take 5 or more years to see the positive effects.

The best approach to reducing exotic species abundance in AGFO will likely include burning; however there may also be a need for targeted herbicides and seeding of native species. Ongoing research on this topic and an upcoming adaptive management initiative for annual brome control in NGPN units should provide more data and guidance to help with these management decisions.

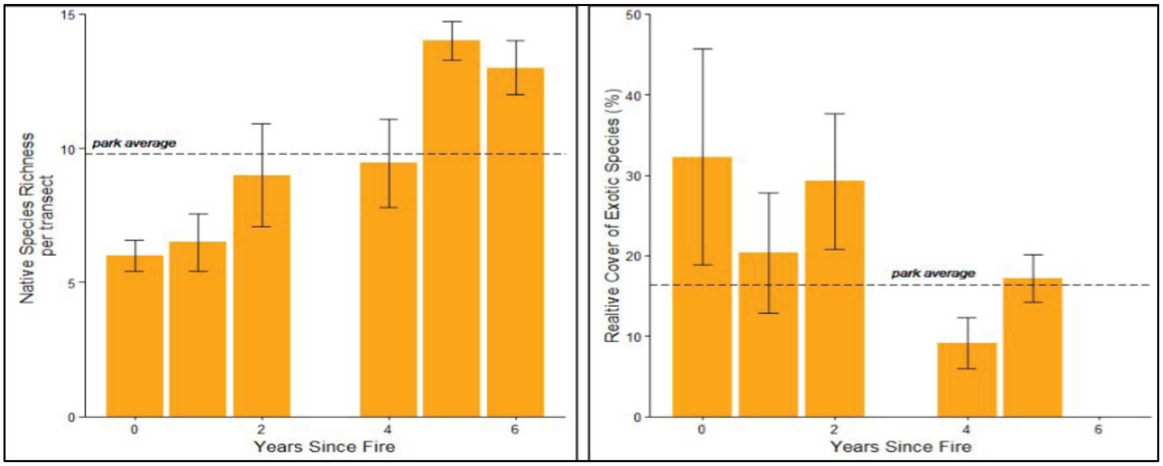


Figure 4.8.12. Native species richness (left panel) and relative percent cover of exotic plants (right panel) across plots with different fire histories (Ashton and Davis 2016). Observations vary between plots that have recently burned (0 years since fire) and plots that had burned 6 years previously (6 years since fire). Bars represent means ± one standard error and sample sizes range from 3 to 9 plots. The dashed line indicates the average native species richness and relative percent cover of exotic species of all plots in AGFO.

Rare Plants

While repeating rare plant surveys and locating rare species is not the focus of NGPN plant community monitoring, we identified 40 rare plant species in AGFO from 1998 to 2015. Of these species, 22 were S3S5 species (vulnerable to secure) whose vulnerability rank is low and uncertain and won't be discussed here (see Appendix A for S3S5 species). Seven critically imperiled (S1) species were observed mostly in very low frequencies and abundances with the exception of slender wheatgrass (*Elymus trachycaulus*), which was observed in 42 plots with 8% mean cover (Table 4.8.4). Other more commonly observed rare species included aridland goosefoot (*Chenopodium dessicatum*, S2S4), longbracted plantain (*Plantago patagonica* S2S4), and hairy goldenaster (*Heterotheca villosa*, S1). Most rare species we observed were in fewer than 5 plots and had less than 0.01% mean cover (Table 4.8.4; Figure 4.8.13). All rare species we observed in AGFO are classified as apparently secure or secure (G4 or G5) at the global scale, but are rare in Nebraska, generally because these species exist on the edge of their global range in the state.

Table 4.8.4. Rare species occurrence in Agate Fossil Beds National Monument sampling plots from 1998–2015. Status ranks are based on Nebraska Natural Heritage Program designations. Plot count is the number of unique plots a species was recorded in across all years. Mean cover is the average cover of that species across all years in plots where cover measurements were recorded.

Species name	Common name	State rank	Global rank	Plot count	Mean cover (%)
Astragalus agrestis	Purple milkvetch	S1	G5	1	0.00
Elymus lanceolatus	Thickspike wheatgrass	S1	G5	1	0.00
Elymus trachycaulus	Slender wheatgrass	S1	G5	42	8.00
Eriogonum cemuum	Nodding buckwheat	S1	G5	3	< 0.01
Heterotheca villosa	Hairy goldenaster	S1	G5	7	0.01
Symphoricarpos albus	Common snowberry	S1	G5	1	0.00
Symphyotrichum falcatum	White prairie aster	S1	G5	1	< 0.01
Euphorbia missurica	Prairie sandmat	S1S3	G5	1	0.00
Erigeron ochroleucus	Buff fleabane	S2	G5	3	0.00
Fritillaria atropurpurea	Spotted fritillary	S2	G5	2	0.00
Phacelia hastate	Silverleaf phacelia	S2S3	G5	1	0.00
Dieteria canescens	Hoary tansyeater	S2S4	G5	1	0.00
Carex hallii	Deer sedge	S2S4	G4	5	0.00
Chenopodium desiccatum	Aridland goosefoot	S2S4	G5	13	0.29
Cryptantha fendleri	Sanddune cryptantha	S2S4	G5	4	0.00
Physaria reediana	Reed's twinpod	S2S4	G4	2	0.00
Plantano patagonica	Longbracted plantain	S2S4	G5	14	0.03
Sphenopholis obtusata	Prairie wedgescale	S2S4	G5	10	0.00

Figure 4.8.13. Photographs of two rare species found in plant community monitoring plots at Agate Fossil Beds National Monument. Left: purple milkvetch (*Astragalus agrestis* S1); Right: spotted fritillary (*Fritillaria atropurpurea* S2). Both species were observed in very low frequencies (figure from Ashton and Davis 2016).

We recommend monitoring of known rare plant populations and a formal rare plant survey be conducted when funds are available. A full rare plant survey will be more likely to thoroughly and accurately quantify the status of rare plants found in AGFO. Any future construction efforts that could disturb native vegetation (e.g. trail building), should avoid damaging species considered rare in Nebraska.

Fossil Hills Trail Paving Project

Fossil Hills Trail is a paved walkway that connects the AGFO visitor center with University and Carnegie Hills. Construction work on the trail was completed in 2007 and resulted in areas of disturbance to native mixed-grass prairie along the trail corridor. We collected data from three plots installed in disturbed prairie habitat and two plots in nearby undisturbed native prairie to evaluate the recovery of the disturbed sites. All of the monitoring sites were impacted by a prescribed fire in May 2009 (James et al. 2009).

There was no statistically significant difference in native species richness (Figure 4.8.14; $F_{2, 6}=0.11$, $P=0.898$) or exotic species relative cover (Figure 4.8.14; $F_{1, 6}=0.70$, $P=0.533$) between disturbed and undisturbed native prairie habitat from 2009–2014. Native species richness in both disturbed and undisturbed habitat was typically equal to, or greater than, the 18-year average native species richness across all plots in AGFO, except in disturbed prairie plots in 2013, which followed a drought year (Figure 4.8.9; Figure 4.8.15). Exotic species relative cover was less than, or equal to, the average exotic species relative cover across the entire monument. Litter cover was greater in disturbed prairie plots from 2009–2014 (Figure 4.8.14; $F_{1, 6}=8.2$, $P=0.029$), and was greater than the 18-year average litter cover in AGFO in 2013 and 2014 in disturbed prairie plots.

Native plant richness is similar in both disturbed and undisturbed plot types and is generally higher in those plots than the AGFO average; however, there are exotic species present in both plot types and there is greater litter cover in disturbed prairie plots. Increased litter cover is associated with a greater risk of exotic brome invasion in Northern Great Plains National Park units (unpublished data), and we suggest continued monitoring of these plots to ensure that any increase in exotic species abundance is detected so appropriate control measures can be taken.

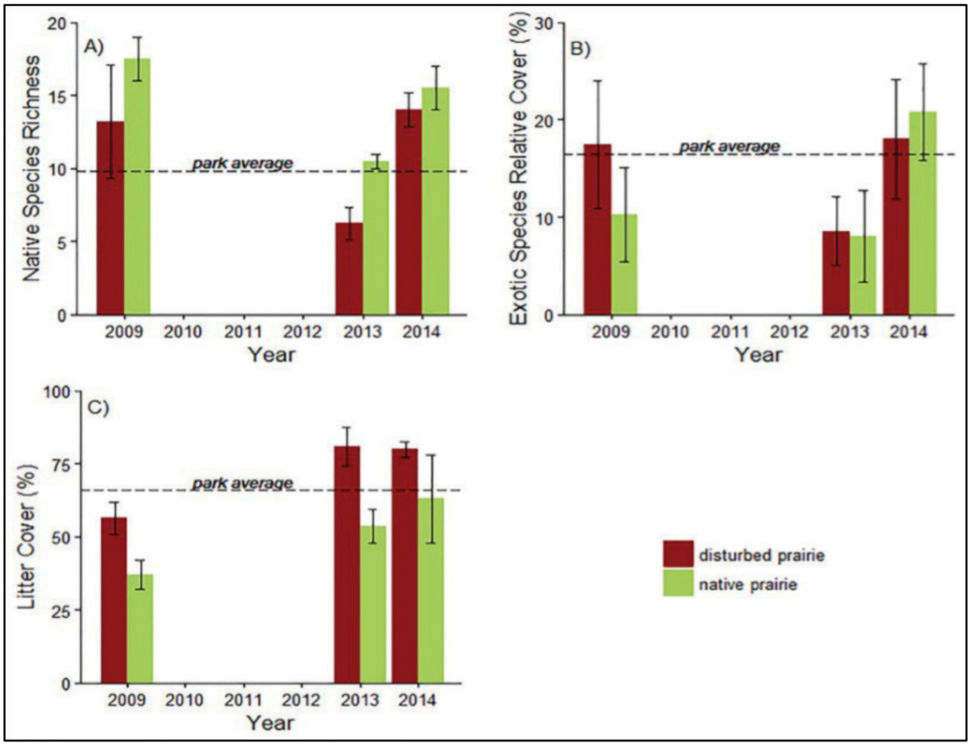


Figure 4.8.14. Native species richness (A), exotic species relative cover (B), and litter cover (C) in intact native mixed-grass prairie and disturbed prairie along the Fossil Hill Trail at Agate Fossil Beds National Monument (mean ± standard error of the mean) (Ashton and Davis 2016). The dashed line indicates the average value for each respective table's attribute across all plots in the park.

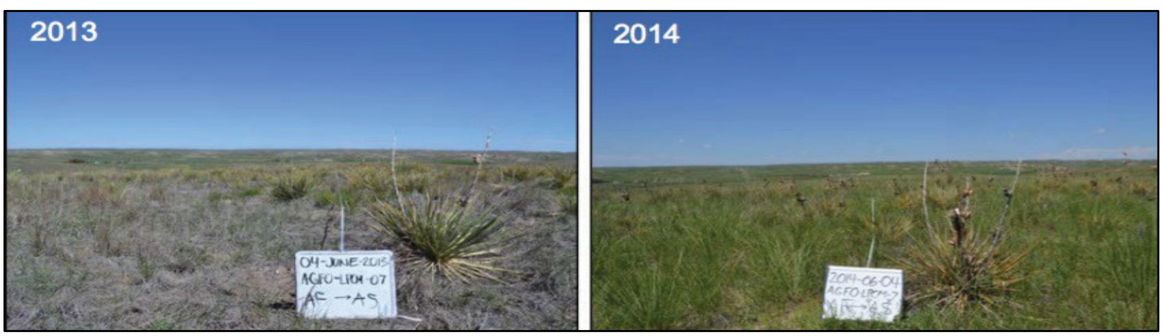


Figure 4.8.15. Images of a prairie plot in AFGO to represent changes in native species richness and exotic species relative cover from 2013 to 2014. Native species richness and exotic species relative cover in disturbed prairie plots were lower in 2013 but had returned to levels similar to 18-year AGFO averages by 2014. This variation was likely in response to drought conditions in 2012, and comparing images of plot LPCM_07 in 2013 and 2014 clearly shows the difference in plant community condition in those years.

<u>The Status of Riparian Vegetation in AGFO</u>

Wetlands along the Niobrara River cover approximately 234 acres within AGFO, or 8% of the monument (Gitzen et al. 2010). We visited 17 riparian monitoring plots in AGFO between 2012 and 2015 (Figure 4.8.16) to estimate the current condition of the plant community and to provide some field data on the extent of pale yellow iris (*Iris pseudacorus*) invasion.

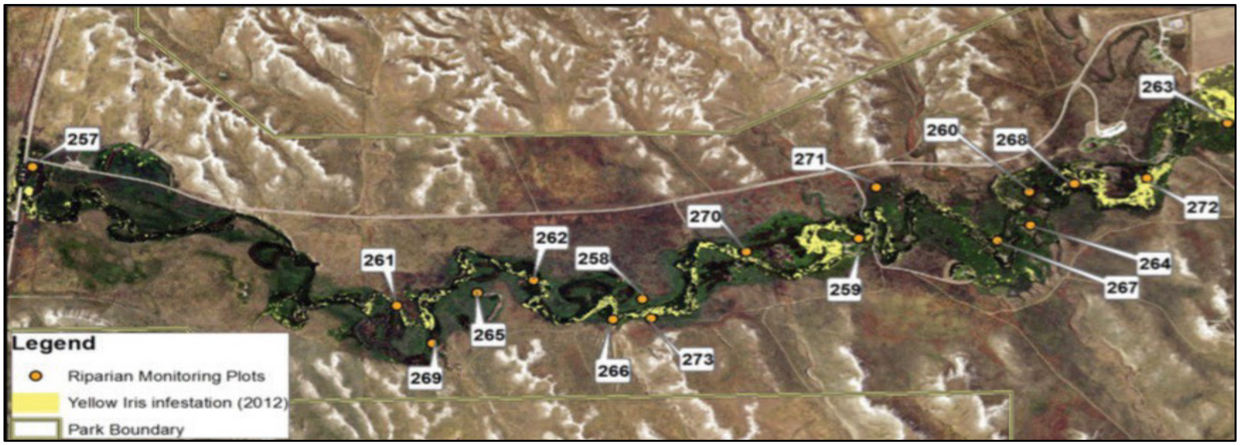


Figure 4.8.16. Location of 17 riparian monitoring plots in Agate Fossil Beds National Monument, 2012–2015 and estimated pale yellow iris infestation in 2012 (Ashton and Davis 2016). The land cover classification was developed by the NGPN in 2012 from 0.6 meter, WorldView-2 satellite imagery collected on June 4, 2012 and refined using field training data sets acquired on June 21, 2012.

We found 88 plant species in the riparian area, and 15 of these were exotic species. Many of the most common species were native graminoids (Figure 4.8.17) including woolly sedge (*Carex pellita*), Baltic rush (*Juncus balticus*), broadleaf cattail (*Typha latifolia*) and western wheatgrass (*Pascopyrum smithii*). Common exotic species included Kentucky bluegrass (*Poa pratensis*) and pale yellow iris (*Iris pseudacorus*). Species richness in the riparian areas was comparable to that of the upland areas. Total species richness averaged 12.2 ± 1.2 species. On average, we recorded 9.6 ± 1.0 native species on each transect. Exotic cover was high, averaging 28.3 ± 2.0 % across the riparian areas of the monument from 2012 to 2015 (Table 4.8.5). Kentucky bluegrass occurred in 12 of 17 plots and averaged over 10.0 ± 1.6 % relative cover throughout the riparian area (Table 4.8.5).

In 2012, it was estimated that 57 acres of the riparian corridor were infested with pale yellow iris (Figure 4.8.16). Pale yellow iris is an Eurasian species that typically grows in temperate freshwater and brackish marsh communities (Sutherland 1990). Its showy flower has made it a favorite ornamental plant and it is now considered invasive across much of North America. Pale yellow iris has the potential to uplift sediments, alter habitat, reduce diversity of native species, and these changes favor its continued spread (Thomas 1980). It was first introduced in the Niobrara basin in 1906 upstream of AGFO in a manmade, spring fed pond on Agate Springs Ranch.

Pale yellow iris was very abundant and found in 11 of 17 sites, averaging 11.5 ± 2.4% relative cover in the riparian area. The distribution of the pale yellow iris is not continuous (i.e., it is not in high abundance at neighboring sites); instead it appears to be patchy across the riparian area (Figure 4.8.16), most often appearing in the wetter sites with the cattails. This patchiness may present a challenge to future control efforts. The abundance of pale yellow iris has stayed fairly constant over the 4 year monitoring period (Table 4.8.5), despite some control efforts in 2015. Future monitoring will be necessary to determine the effectiveness of the treatment program over time.

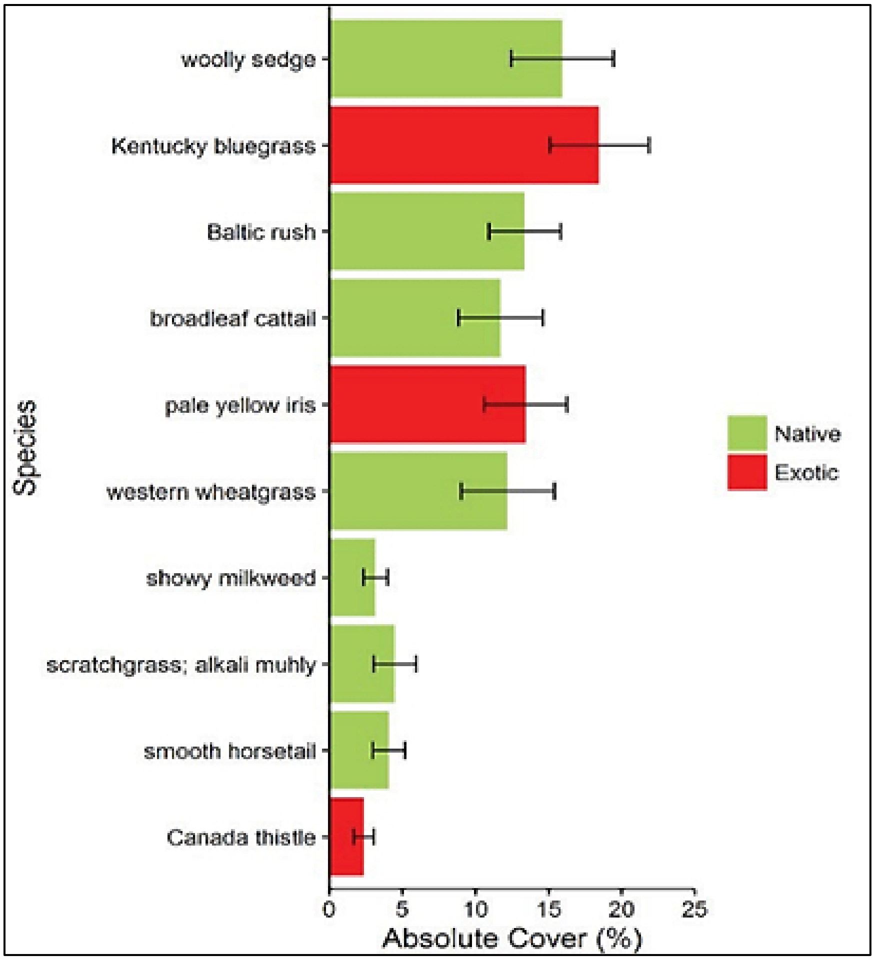


Figure 4.8.17. The average absolute cover of the 10 most common native (green) and exotic (red) riparian plants recorded at Agate Fossil Beds National Monument in 2015 (Ashton and Davis 2016). Bars represent means ± standard errors. Kentucky bluegrass and pale yellow iris were the most common exotic species.

Table 4.8.5. The relative percent cover of pale yellow iris in monitoring plots at Agate Fossil Beds National Monument 2012–2015.

Year	Number of plots	Relative cover of exotic species (% mean ± se)	Relative cover of Kentucky bluegrass (% mean ± se)	Relative cover of yellow iris (%mean ± se)	Minimum relative cover of yellow iris (%)	Maximum relative cover of yellow iris (%)
2012	12	28.1 ± 4.7	11.9 ± 3.6	11.4 ± 5.1	0	48.2
2013	11	31.0 ± 5.0	9.8 ± 3.9	10.6 ± 6.0	0	57.1
2014	12	31.9 ± 3.9	10.1 ± 3.2	14.1 ± 5.9	0	54.3
2015	17	24.2 ± 3.3	8.7 ± 2.8	10.1 ± 3.3	0	40.4

4.8.4. Conclusion

The Northern Great Plains Inventory & Monitoring Program and Fire Effects Program have been monitoring vegetation in Agate Fossil Beds National Monument for over 18 years. While methods have changed slightly, this report summarizes data from over 64 locations from 1998–2015. Below, we list the questions we asked and provide a summarized answer, for more details see the Results and Discussion section. We conclude with a Natural Resource Condition Table (Table 4.8.6) that summarizes the current status and trends in a few key vegetation metrics.

Table 4.8.6. Natural resource condition summary table of plant communities in AGFO. Current values are based on data from 2011–2015 and trends are based on data from 1998–2015.

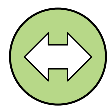
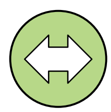
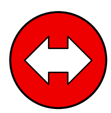
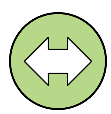
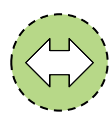
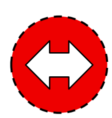
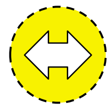
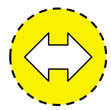
Indicator	Measure	Current value (mean ± se)	Reference condition and data sources	Condition /trend	Condition rationale
Upland plant community structure and composition	Native species richness (1m^2 quadrats)	7.3 ± 0.5 species	3–15 species		AGFO plays a vital role in protecting and managing some of the las remnants of native mixed-grass prairie in the region. The monument is characterized by moderate native species richness, but average richness is within a natural range of variability (Symstad and Jonas 2014). The lowest native diversity is found near the road.
	Evenness (native spp. Point-intercept transects)	0.70 ± 0.01	To be determined		Native evenness has not changed since monitoring began in 1998.
	Relative cover of exotic species	17.6 ± 2.5%	<10% cover		AGFO maintains a mixed-grass prairie with modern exotic plant cover and a fair diversity of native plants.
	Annual brome cover	7.4 ± 1.9%	<10% cover		Annual invasive bromes are not currently abundant in AGFO, but active management may be required to keep such low cover.
Riparian plant community structure and composition	Native species richness (50m point-intercept transect)	9.6 ± 1.0	To be determined		The riparian areas of AGFO had levels of diversity similar to the upland areas
	Relative cover of exotic species	28.3 ± 2.0%	≤ 10% cover		The relative cover of exotic species in the riparian areas of AGFO was very high. Exotic control efforts should be focused in this area to restore native plant diversity and ecological integrity.

Table 4.8.6 (continued). Natural resource condition summary table of plant communities in AGFO. Current values are based on data from 2011–2015 and trends are based on data from 1998–2015.

Indicator	Measure	Current value (mean ± se)	Reference condition and data sources	Condition /trend	Condition rationale
Riparian plant community structure and composition (continued)	Relative cover of pale yellow iris	11.5 ± 2.4%	≤ 10% cover		Pale yellow iris has invaded riparian areas throughout the monument. It had a patchy distribution and was absent in some sites while accounting for over 50% in others.
Overall condition for all indicators and measures					–

What is the current status of plant community composition and structure of AGFO grasslands (species richness, cover, and diversity) and how has this changed from 1998 to 2015?

Native grasses, such as needle and thread, sand reed, and western wheat-grass, are abundant and the dominant component of the prairie at AGFO. Native plant diversity is at a moderate level compared to other grasslands in the region (Table 4.8.6), but diversity is spatially variable. We found no significant trends in native diversity or evenness from 1998 to 2015, but both may become threatened if cover of annual invasive brome grasses increases, as we've observed in other Northern Great Plains Inventory and Monitoring units (Figure 4.8.9).

How do trends in grassland condition correlate with climate and fire history?

Native species richness increased in years with more rainfall and a hot dry year in 2012 corresponded to large declines in native species richness and an increase in exotic species cover. Plots that had not burned in 5 or 6 years had a higher number of native species and a lower cover of exotics than sites that burned more recently and when compared to AGFO averages (Figure 4.8.13). This suggests that prescribed fire can benefit the mixed-grass prairie in AGFO, but it may take 5 or more years to see the positive effects following a burn.

What, if any, rare plants were found in AGFO long-term monitoring plots?

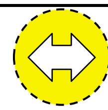
We identified 22 rare plant species in AGFO between 1998 and 2015; seven of these are considered critically imperiled within Nebraska. We recommend monitoring of rare plant populations and more targeted surveys of rare plant species be completed when funds are available.

How did installation of the AGFO Fossil Hills Trail affect the adjacent prairie?

The disturbed prairie adjacent to the Fossil Hills Trail is very similar to the native prairie in other parts of AGFO. This suggests that the prairie in AGFO is resilient and can recover from a moderate level of disturbance. We suggest continued monitoring of these plots to ensure that any increase in exotic species abundance is detected so appropriate control measures can be taken.

What is the composition and structure of the riparian corridor at AGFO?
The riparian corridor in AGFO is a fairly diverse assemblage of riparian species such as sedges, willows, and cattails. It is, however, more invaded than the upland areas of AGFO and threatened by high cover of Kentucky bluegrass and pale yellow iris. Since riparian monitoring began in 2012, we have not detected a significant change in the cover of pale yellow iris. Continued monitoring is necessary to determine if exotic treatment is effective over the long-term.

4.8.5. Vegetation Overall Condition



Condition: Warrants Moderate Concern
Confidence: Low
Trend: Unchanging

Condition
Overall vegetation condition was determined by the average of the indicator conditions. The NRCA authors summarized the condition, confidence, and trend for each indicator, and assigned condition points. The score for overall vegetation condition was 64 points, which placed vegetation at Agate Fossil Beds NM in the W*arrants Moderate Concern* category.

Confidence
Confidence was Low for Riparian Plant Community Structure and Composition (three measures) and Medium for Upland Plant Community Structure and Composition (four measures). The score for overall confidence was 29 points, which met the criteria for *Low* confidence in overall vegetation condition.

Trend
Trend was *Unchanging* for all measures and indicator, and overall trend for vegetation was *Unchanging.*

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4.9. Breeding Birds

4.9.1. Background and Importance

Birds are a critical natural resource that provide an array of ecological, aesthetic, and recreational values. As a species-rich group, they encompass a broad range of habitat requirements, and thus may serve as indicators of landscape health (O'Connell et al. 2000). Bird communities can reflect changes in habitat (Canterbury et al. 2000), climate (Walther et al. 2002), ecological interactions (e.g., Gurevitch and Padilla 2004), and other factors of concern in ecological systems.

Parks may serve as reference sites for interpreting regional and national population trends, and the NPS has made a commitment to monitoring landbirds (Gitzen et al. 2010). Protecting birds is key to park integrity, and park units may serve as "islands" of intact habitat for birds regionally (e.g., Goodwin and Shriver 2014).

In 2013, the NPS Northern Great Plains Network (NGPN) began region-wide landbird monitoring in collaboration with the Bird Conservancy of the Rockies (formerly the Rocky Mountain Bird Observatory) and as part of a larger effort, the Integrated Monitoring in Bird Conservation Regions (IMBCR) program. The objectives of these ongoing monitoring efforts are: 1) estimate the proportion of sites occupied (occupancy estimates) for breeding birds, 2) identify changes in community dynamics, 3) estimate changes in the densities of common breeding landbirds, and 4) relate changes in environmental parameters to bird population trends.

The grasshopper sparrow is an important grassland species found at Agate Fossil Beds NM (Photo by Dominic Sherony, 2005).

<u>History of Bird Surveys at Agate Fossil Beds National Monument</u>

Agate Fossil Beds NM lists 124 species as "present" in the park, 7 species as "probably present," and 42 species as "unconfirmed" (https://irma.nps.gov/NPSpecies). The first intensive inventory of birds was conducted in the 1990s (Graetz et al. 1995). Graetz and others detected 92 bird species through transects, point counts, and road surveys in 1992–1994. They reported the densities of each species within four habitat types.

Early monitoring efforts conducted from 2001–2003 detected 46 species in variable circular plot surveys (Peitz and Rowell 2003). As part of developing the current inventory and monitoring program in the NGPN, bird surveys were conducted in 2010 throughout Agate Fossil Beds NM (Stenger et al. 2011). Fifty-five species were detected in point transects during peak breeding.

In the NGPN group of parks to which Agate Fossil Beds NM belongs, landbirds are considered a "vital sign" of park ecosystems (Gitzen et al. 2010). Monitoring of landbirds began in 2013 with help from the Bird Conservancy of the Rockies. This conservation group established 97 permanent point count locations, detecting 52 species in 2013, 40 species in 2014, and 52 species in 2015.

Regional Context

Agate Fossil Beds NM is located within the shortgrass prairie bird conservation region (BCR 18; Figure 4.9.1). The shortgrass prairie is an arid region with limited vegetation height and diversity. Some of North America's highest priority birds breed here, including the grasshopper sparrow (Figure 4.9.2), a species that can be found at Agate Fossil Beds NM.

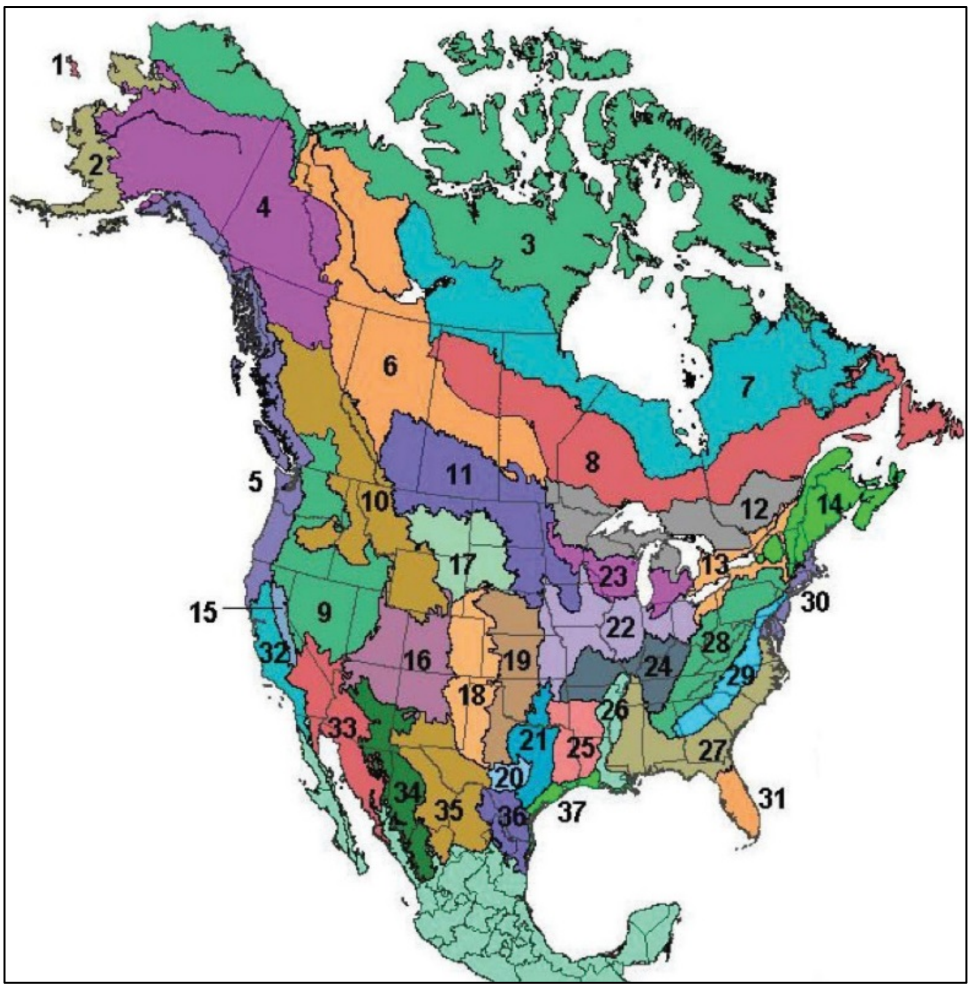

Figure 4.9.1. Bird conservation regions of North America (BCRs; www.nabci-us.org/map.html). Agate Fossil Beds National Monument is located within BCR18, the shortgrass prairie bird conservation region.

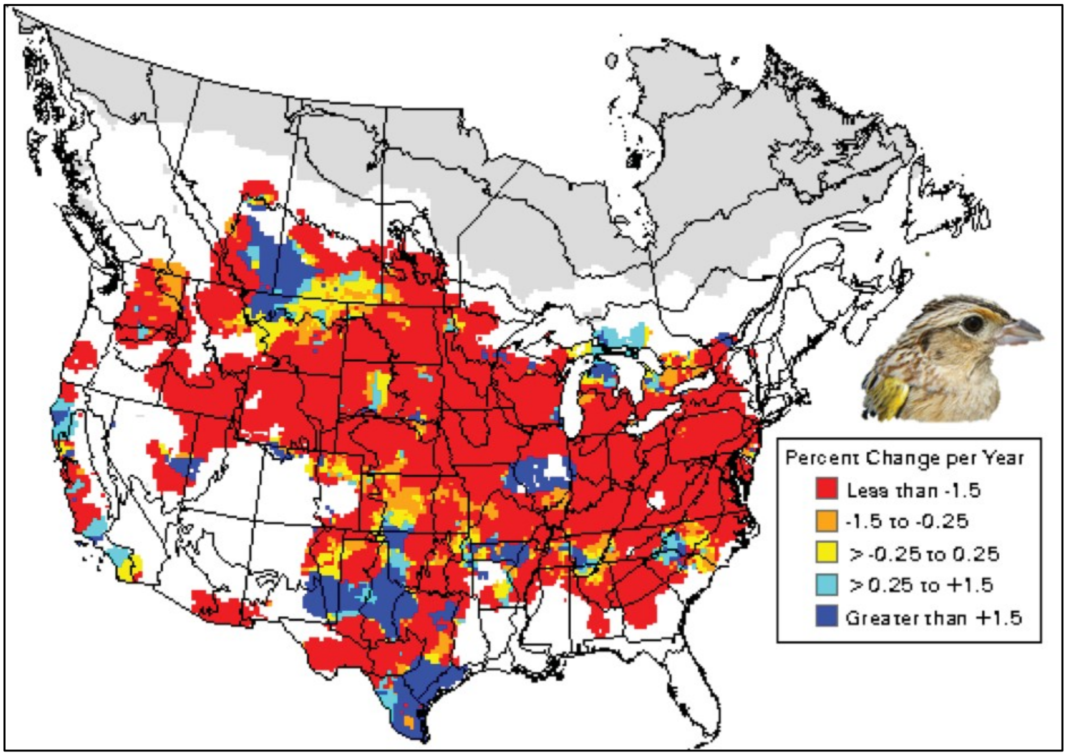

Figure 4.9.2. Population trends for the grasshopper sparrow from 1963 to 2013. The grasshopper sparrow is an example of a grassland species that has been declining for a variety of reasons, including habitat loss and degradation. This map shows population trends from 1963–2013 (Map courtesy of USGS and BBS, image from Wikipedia).

Most grassland bird species are declining in North America (Peterjohn and Sauer 1995, Sauer et al. 2003). While the overall trend for birds in the shortgrass BCR is stable (Sauer et al. 2003), all of the grassland-obligate species there exhibit negative trends (Sauer et al. 2003, Sauer and Link 2011).

The causes of declines in species such as the grasshopper sparrow are poorly understood but could be related to a reduction in the diversity of native herbivores, such as bison and prairie dogs that create high quality habitat for many grassland bird species.

Another source of important bird habitat within Agate Fossil Beds NM is the riparian area associated with the Niobrara River (Figure 4.9.3). Loss of riparian habitat is another major cause of bird declines regionally (DeSante and George 1994).

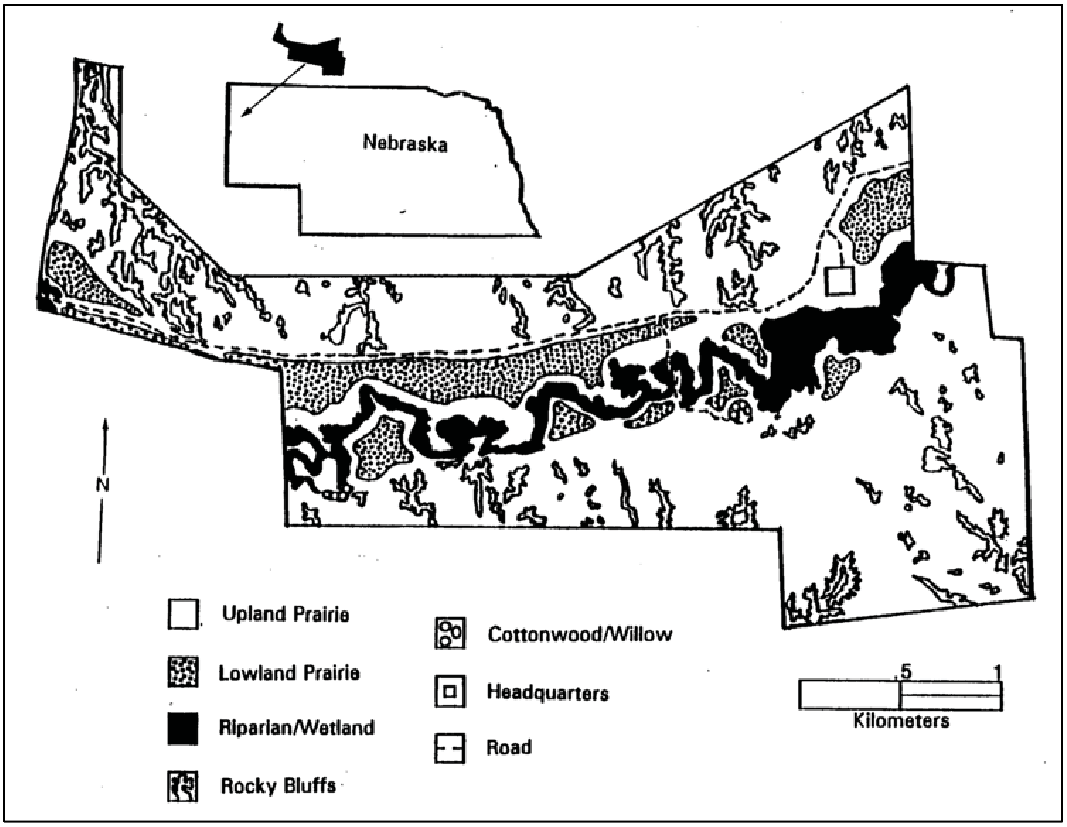

Figure 4.9.3. Agate Fossil Beds NM provides a variety of habitats for birds and other wildlife (Graetz et al. 1995).

4.9.2. Breeding Birds Standards

The Migratory Bird Treaty Act of 1918 (16 U.S.C. 703–712; Ch. 128; July 13, 1918; 40 Stat. 755) protects hundreds of bird species by prohibiting the take (i.e., to kill, injure, harm, annoy, etc.) of any species of migratory bird without a permit. This act provides formal protection to most bird species that can be found at Agate Fossil Beds NM. Of the 118 species considered to be present or probably present at Agate Fossil Beds NM, 20 species are considered species of federal concern. However, none of the birds at Agate Fossil Beds NM are formally protected under the Endangered Species Act. Both bald and golden eagles are protected under the Bald and Golden Eagle Act.

PIF maintains a list of all bird species in North America with population estimates and "priority ranking" scores. These scores are a quantitative way of assessing risk based on population trends and species traits. PIF also publishes a Watch List that identifies the species most in need of conservation action based on priority rankings (Figure 4.9.4).

Figure 4.9.4. Perched lark bunting. Based on the Partners in Flight ranking system, the lark bunting was the highest priority species observed at Agate Fossil Beds NM in 2015 (NPS photo).

Several Yellow Watch List species can be found at Agate Fossil Beds NM, including chestnut-collared longspur and McCown's longspur.

Nebraska's State Wildlife Action Plan contains a list of species of greatest conservation need. Seven of 22 species designated as globally or nationally at risk ("Tier I At-risk Species") can be found at Agate Fossil Beds NM: chestnut-collared longspur, ferruginous hawk, loggerhead shrike, long-billed curlew, McCown's longspur, pinyon jay, and short-eared owl. Additionally, 13 of 61 species designated as at-risk within Nebraska ("Tier II At-risk Species") can be found at Agate Fossil Beds (Figure 4.9.5).

Figure 4.9.5. Perched Wilson's snipe. Wilson's snipe is a Nebraska Tier II At-Risk Species that was commonly observed in 2015 (Wikipedia photo).

4.9.3. Methods

Indicators and Measures

We assessed overall bird condition based on three indicators: species diversity, species abundance, and conservation value. Each of these indicators contributes to different aspects of bird condition. We used measurements specified by the scientific literature and expert opinion. There was no clear or accepted standard for assigning indicator conditions, so we instead illustrate a framework that could be used to assess bird condition over time.

Indicator: Species Diversity

Species diversity informs us about the composition and number of bird species. There are a variety of ways to measure species diversity, including the most basic measure: the number of species, or species richness.

Measure of Species Diversity: Species Richness

Species richness is a basic measure of ecological diversity and integrity. Apart from the inherent value of species richness, a greater number of species also tends to reflect the quality and diversity of habitat. Because the study design of the current monitoring effort is the same from year to year, we can use data from these surveys as comparable estimates of the number of species observed over time.

Sampling effort (number of point-transects conducted) and the number of species observed may vary from year to year at Agate Fossil Beds NM. Imperfect detection of species can make inter-annual comparisons of species lists unreliable indicators of species that were actually present in the park unit. Occupancy estimates take these factors into account, and incorporate imperfect detection in estimates. The particular type of model used to generate estimates for IMBCR sites is a multi-scale occupancy model (Nichols et al. 2008, Pavlacky et al. 2012). This type of model assumes that there are no misidentifications of species that are not present (i.e., that there are no false positive observations). In the case of Agate Fossil Beds NM, occupancy estimates (y) can be interpreted as the proportion of the park in which the species is expected to be found. These values may range from zero to one. Even if a species was not detected in a given year, it may have a non-zero probability of occupying the park. An occupancy estimate of one would indicate that a particular species would be expected to occur in all locations.

These occupancy estimates provide one measure of species richness (A. Green, personal communication 20 May 2016). By summing the occupancy estimates across all species, we generated a value that we interpreted as the average species richness across the park unit, or the number of species expected in a particular survey location. We present this value with its standard error, which describes the precision of the species richness estimate. We calculated standard error using the delta method (Powell 2007). We first calculated the variance of each species-specific estimate of occupancy (standard error squared), summed the variance estimates across all species, and calculated the standard error of the richness estimates (square root of the summed variances). For our calculation of average species richness, we assigned birds that were observed but for which occupancy estimates were lacking (22–26% of species) a value of 0.01 and a standard error estimate of 0.01.

In general, species lacking occupancy estimates were observations of a single individual in a given year. In the future, the Avian Data Center will likely provide occupancy estimates for all species observed. All data are freely available online (http://rmbo.org/v3/avian/ExploretheData.aspx).

Indicator: Species Abundance

Bird population abundance can respond to both short- and long-term drivers of habitat quality, such as vegetation structure, prey abundance, and competition or predation pressures.

Measure of Species Abundance: Mean Density

The Bird Conservancy tracks number of individuals per square kilometer over time along with precision estimates. Density estimates are derived from count data that have been corrected for imperfect detection (under-detection). All data are freely available online (http://rmbo.org/v3/avian/ExploretheData.aspx).

Indicator: Conservation Value

Maximizing species richness and density is generally desirable, but these measures do not tell us about the identities of the bird species present. For example, we would value a bird community of native species more highly than one with the same number of non-native species. As another example, one would not typically manage for increased densities of introduced nest parasitic bird species. This consideration led us to ask what we know about the conservation value of individual species, or of Agate Fossil Beds NM as a whole. The PIF database offers a way to assess the value of species or groups of species through the priority ranking list.

There have been a number of attempts at creating indices to rate bird communities at different spatial scales. One example is the bird community index developed for portions of the eastern United States (O'Connell et al. 2000). This index requires placing birds into guilds, and is a good indicator of habitat quality condition in those regions. This approach has been applied to National Parks in the Northeast and National Capital NPS regions to compare bird communities between parks and outside protected areas (Goodwin and Shriver 2014). This index has not been developed for the region in which Agate Fossil Beds NM resides, so we were unable to use this approach for the Natural Resource Condition Assessment.

We used an alternative approach to assess the conservation value of bird communities, rooting our calculations in the Partners in Flight (PIF) priority rankings (Hunter et al. 1993). Bird species in the PIF database are prioritized at both the regional (bird conservation region) and continental scales (Partners in Flight Science Committee 2012). Each species is independently ranked from one (low vulnerability) to five (high vulnerability) along the Partners in Flight Species Assessment Factors, and these category rankings may be summed to give an overall priority score for the species (from the Partners in Flight Handbook on Species Assessment Version 2012 [Committee 2005]):

- **Breeding Distribution (BD):** indicates vulnerability due to the geographic extent of a species' breeding range on a global scale.
- **Population Size (PS):** indicates vulnerability due to the total number of adult individuals in the global population.

- **Population Trend (PT)**: indicates vulnerability due to the direction and magnitude of changes in population size within North America since the mid-1960s.
- **Threats to Breeding (TB):** indicates vulnerability due to the effects of current and probable future extrinsic conditions that threaten the ability of populations to survive and successfully reproduce in breeding areas within North America.
- **Relative Density (RD)**: reflects the mean density of a species within a given BCR relative to density in the single BCR in which the species occurs in its highest density.

The criteria are assessed either at the level of the entire species range (global score) or the level of the region (regional score). These criteria are breeding distribution (global score), population size (global score), population trend (regional score), threats to breeding (regional score), and breeding relative density (regional score). The sum of these values is the regional concern score for breeding. The range of possible scores for each species at the level of the bird conservation region therefore is 5–25, with five being the lowest priority ranking and 25 being the highest.

The PIF species concern scores may be used to set conservation priorities (Carter et al. 2000). PIF-based conservation value scores may be refined by the use of species abundance to weight the PIF rankings (Nuttle et al. 2003). A comparison of the bird community index and the PIF-based conservation value approaches demonstrated the utility of the PIF method (O'Connell 2009); the two indices were strongly correlated, even when using a simple sum of PIF scores. All data are freely available online (http://rmbo.org/pifdb).

Measure of Conservation Value: Mean Priority Rankings

We averaged the regional ranking for each species, excluding introduced species. Other approaches to assessing conservation value include summing rankings (O'Connell 2009), or weighting scores by abundance or occupancy (Nuttle et al. 2003). For simplicity's sake and ease of interpretability, we present an average ranking with its standard error here.

Data Collection and Sources

Data Management and Availability

For this assessment, we used data from two online database sources. Data on all bird species from monitoring surveys are stored on the Rocky Mountain Avian Data Center website and managed by the Bird Conservancy of the Rockies. Data for priority rankings of landbirds are stored on the Partners in Flight Species Assessment Database website and also managed by the Bird Conservancy.

Field Protocol

Monitoring of birds at Agate Fossil Beds NM began in 2013 following a standardized protocol (Beaupré et al. 2013). Up to 97 permanent point-transect locations were surveyed each year (Figure 4.9.6) (Buckland et al. 2001). Each of these locations was surveyed for birds seen or heard calling during morning hours (beginning 30 minutes before local sunrise) at the height of the breeding season (May 15 – June 14; Beaupre et al. 2013). This approach tends to under-sample certain groups such as nocturnal birds, while sampling groups such as passerines well (Buckland 2006). By recording the distance to each observation, researchers are able to create a detection function that can be used in the calculation of bird densities (Buckland 2006). Repeat observations at sampling locations allow researchers to correct for under-detection of the number of sites occupied (MacKenzie et al. 2002).

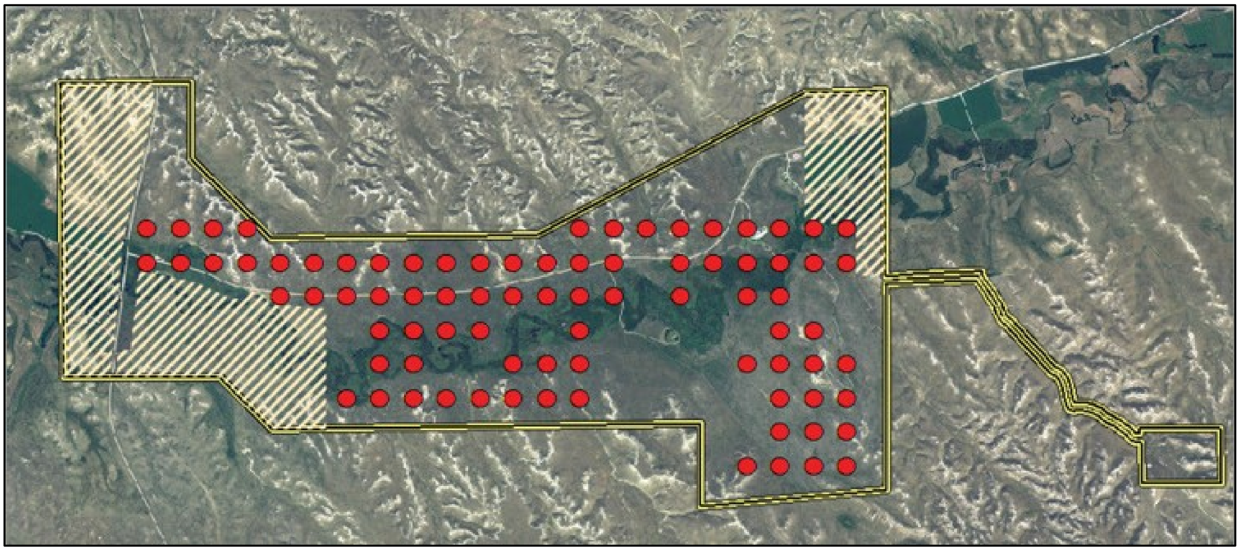

Figure 4.9.6. Bird monitoring at Agate Fossil Beds NM includes 97 point-transect locations (Buckland et al. 2001). The surveys are located in native grassland and the riparian area along the Niobrara River.

Quantifying Breeding Bird Condition, Confidence, and Trend

Indicator Condition

To assess indicator condition, we used methods informed by expert opinion and described by Nuttle et al. (2003). For species not formally protected by the Endangered Species Act, calculating bird condition is not straightforward. To calculate a condition score, we would have needed empirically derived estimates of the levels of species diversity, species abundance, and conservation values that revealed the condition of the species within the park unit. Those criteria are absent from the literature, and assigning a condition score without them would have been unwarranted. In lieu of condition scores, we present values for indicators based on the best available data; natural resource managers can reference these values in current and future park planning.

The results for Agate Fossil Beds NM are presented along with a comparison of the same calculations at the level of the bird conservation region. IMBCR is working to develop complete coverage of BCR18, but is still in the process of adding new monitoring locations. For this reason, BCR-wide estimates were not currently available. Here we present results for the Colorado portion of BCR18, since this state accounted for 75% of all sampling locations in 2015.

Occupancy, density, and count data were extracted from the Avian Data Center for using “NE-BCR18-AF” as the “individual stratum” for Agate Fossil Beds NM and the “superstratum: CO-BCR18” for the Colorado portion of BCR18.

Indicator Trend

Calculating a trend estimate requires sufficient statistical power and surveys were designed with this in mind. However, detecting a trend based on the IMBCR survey design will likely require at least five years of continued monitoring. The monitoring program at Agate Fossil Beds NM is relatively new, having commenced in 2013, so data were not sufficient at the time of this assessment to calculate trends in bird populations.

Indicator Confidence

Confidence ratings were based on data availability (number of years) and data quality (e.g., survey design, estimation techniques). We gave a rating of *High* confidence when surveys were conducted regularly, data were collected recently, and the data were collected methodically. We assigned a *Medium* confidence rating when surveys were not conducted regularly, data were not collected recently, or data collection was not repeatable or methodical. *Low* confidence was assigned when there were no good data sources to support the condition.

<u>Overall Breeding Bird Condition, Trend, and Confidence</u>

We deferred to the expert scientific community to assign an overall breeding bird condition, trend, and confidence.

4.9.4. Breeding Bird Conditions, Confidence, and Trends

<u>Species Diversity</u>

Condition: Not Available
Confidence: High
Trend: Not Available

Condition

To calculate species diversity, we used results from point transect surveys conducted from 2013–2015 (Table 4.9.1, Figure 4.9.7). Across 64 point-transect locations, 52 species were observed in 2013. Across 82 point-transect locations, 40 species were observed in 2014. Across 97 point-transect locations, 52 bird species were observed in Agate Fossil Beds in 2015. Of these observations, four non-native species were observed from 2013–2015 (Eurasian collared-dove, European starling, ring-necked pheasant, and rock pigeon). These introduced species were excluded from richness estimates.

Table 4.9.1. Average species richness of breeding birds at Agate Fossil Beds NM (AGFO) and within the Colorado portion of the shortgrass prairie bird conservation region (BCR18).

Location	Year	Number of locations surveyed	Number of species observed	Number of species with occupancy estimates	Number of non-native species	Average species richness ± standard error
AGFO	2013	64	52	29	3	19.34 ± 1.31
	2014	82	40	31	1	16.69 ± 1.39
	2015	97	52	37	2	19.35 ± 1.53
BCR18	2013	971	150	106	5	10.17 ± 0.43
	2014	938	148	101	5	9.43 ± 0.41
	2015	1832	161	114	5	10.06 ± 0.44

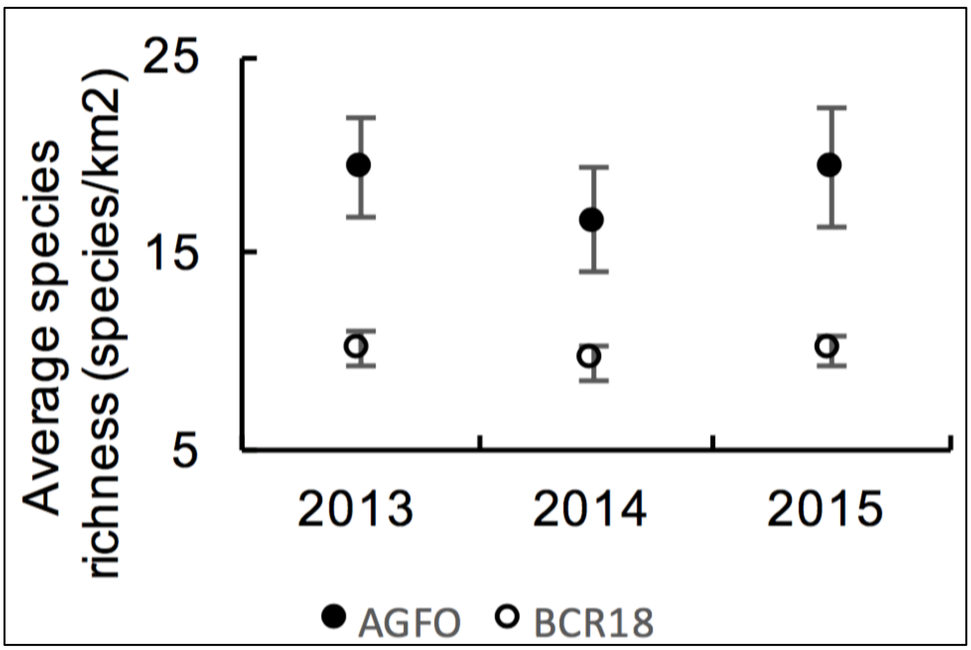

Figure 4.9.7. Average species richness with 95% confidence intervals of breeding birds within Agate Fossil Beds NM and the Colorado portion of the shortgrass prairie bird conservation region (BCR18).

While species richness for Agate Fossil Beds NM was nearly double the richness of the BCR in which the park is situated, reference criteria were unavailable to identify what amount of richness constituted good or bad condition. Condition for species richness was *Not Available*.

Confidence

We calculated species diversity from high-quality occupancy estimates from three years of monitoring data from up to 97 locations within the park. The confidence was *High*.

Trend

There were three years of point-transect data available from Agate Fossil Beds NM. A similar number of species was observed in each year, with the fewest number (40) being observed in 2014. It was too early to calculate a trend in species richness at the time of this assessment, but the richness estimates were similar among the three survey years.

<u>Species Abundance</u>

Condition: Not Available
Confidence: High
Trend: Not Available

Condition

We examined species abundance across three years of monitoring data (Table 4.9.2, Figure 4.9.8). We used available density estimates for native species to calculate an average density for the study area (number of birds per kilometer^2). In general, density estimates should be fairly sensitive to short-term changes in habitat quality, such as food availability.

Table 4.9.2. Average density of breeding birds at Agate Fossil Beds NM (AGFO) and within the Colorado portion of the shortgrass prairie bird conservation region (BCR18). The number of species is all native species for which there were density estimates.

Location	Year	Number of locations surveyed	Number of species observed	Number of species with density estimates	Number of non-native species	Average density ± standard error
AGFO	2013	64	52	36	3	8.11 ± 0.99
	2014	82	40	33	1	9.62 ± 1.98
	2015	97	52	45	2	6.94 ± 0.63
BCR18	2013	971	197	87	5	2.61 ± 0.15
	2014	938	178	97	5	3.07 ± 0.21
	2015	1832	187	90	5	3.50 ± 0.25

While species abundance at Agate Fossil Beds NM was nearly triple species abundance of the BCR in which the park is situated, reference criteria were unavailable to identify what abundance numbers constituted good or bad condition. Condition for species abundance was *Not Available.*

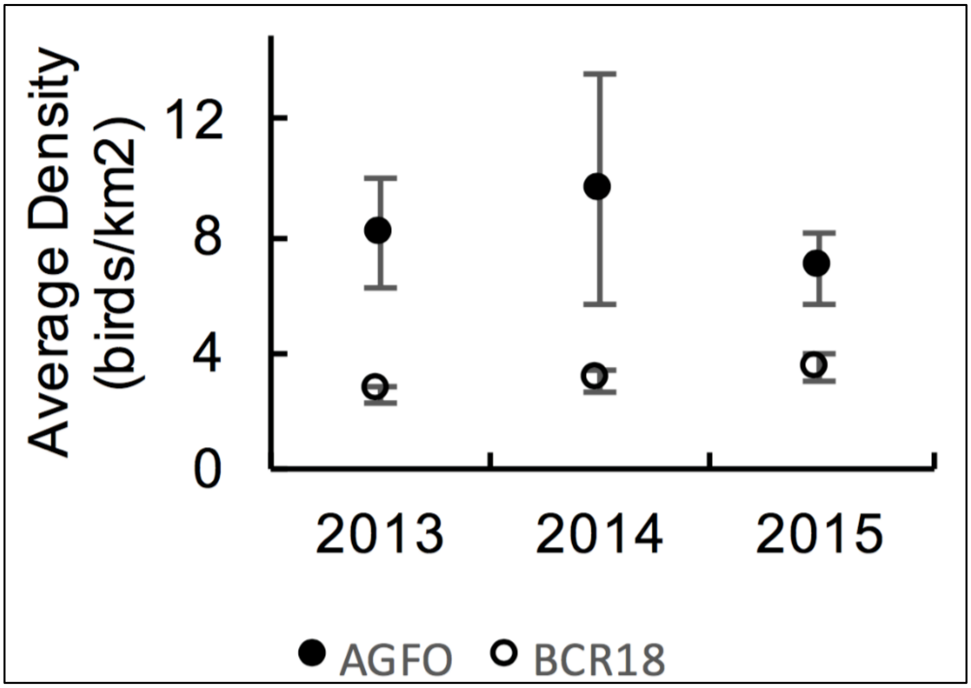

Figure 4.9.8. Average density with 95% confidence intervals of breeding birds within Agate Fossil Beds NM and the Colorado portion of the shortgrass prairie bird conservation region (BCR18).

Confidence

Species abundance was calculated from high-quality occupancy estimates from three years of monitoring data from up to 97 locations within the park. The confidence was *High*.

Trend

There were three years of point count data available from Agate Fossil Beds NM. The highest average densities were observed in 2014 (approximately 9 birds/kilometer^2). The most abundant bird species was the red-winged blackbird in all three years (34 birds/kilometer^2 in 2013, 79 in 2014, and 77 in 2015). It was too early to calculate a trend in species abundance at the time of this assessment, but the density estimates varied among the three survey years.

<u>Conservation Value</u>

Condition: Not Available
Confidence: High
Trend: Not Available

Condition

To assess conservation value, we used park monitoring data combined with Partners in Flight priority rankings (Table 4.9.3, Figures 4.9.9 and 4.9.10). The combination of more species present at a park and/or the higher priority rankings of individual species increases the conservation value of the park unit.

Table 4.9.3. Conservation value score of native breeding landbirds at Agate Fossil Beds NM and within the shortgrass prairie bird conservation region (BCR18).

Location	Year	Number of locations surveyed	Number of species observed	Number of ranked species	Number of non-native species	Average priority ranking ± standard error
AGFO	2013	64	52	38	3	10.87 ± 0.40
	2014	82	40	30	1	11.30 ± 0.47
	2015	97	52	35	2	11.20 ± 0.43
BCR18	2013	971	149	110	5	11.18 ± 0.24
	2014	938	145	106	5	11.15 ± 0.23
	2015	1832	159	121	5	11.18 ± 0.22

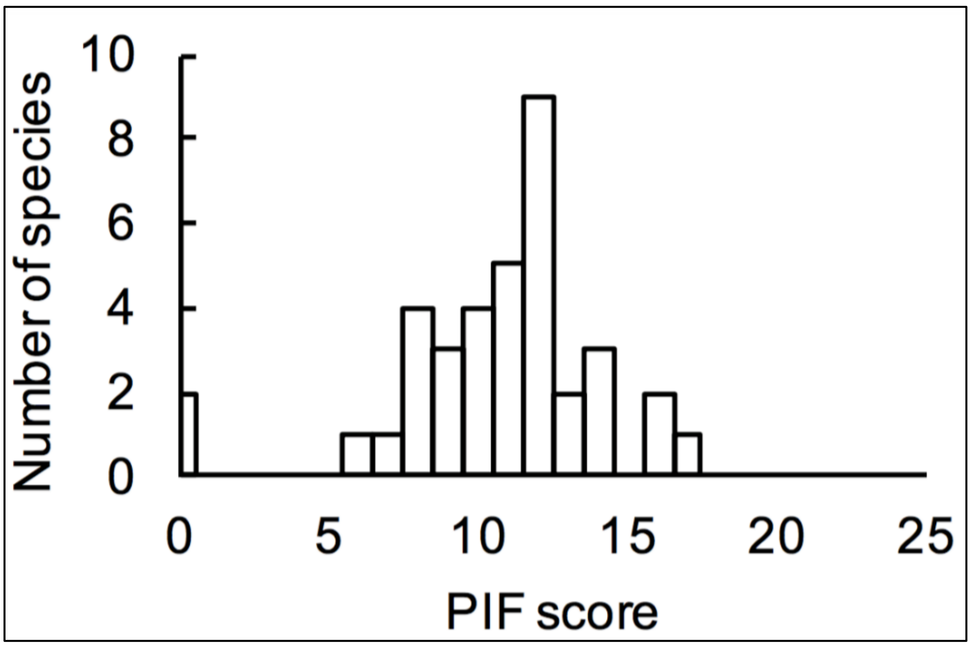

Figure 4.9.9. The distribution of Partners in Flight priority rankings for landbird species seen in 2015 at Agate Fossil Beds NM. The average ranking was 11.2 ± 0.4 out of a total possible score of 25. We assigned two non-native species a rank of zero. The lowest ranked native species was American robin with a score of six. The highest ranked native species was lark bunting with a score of 17.

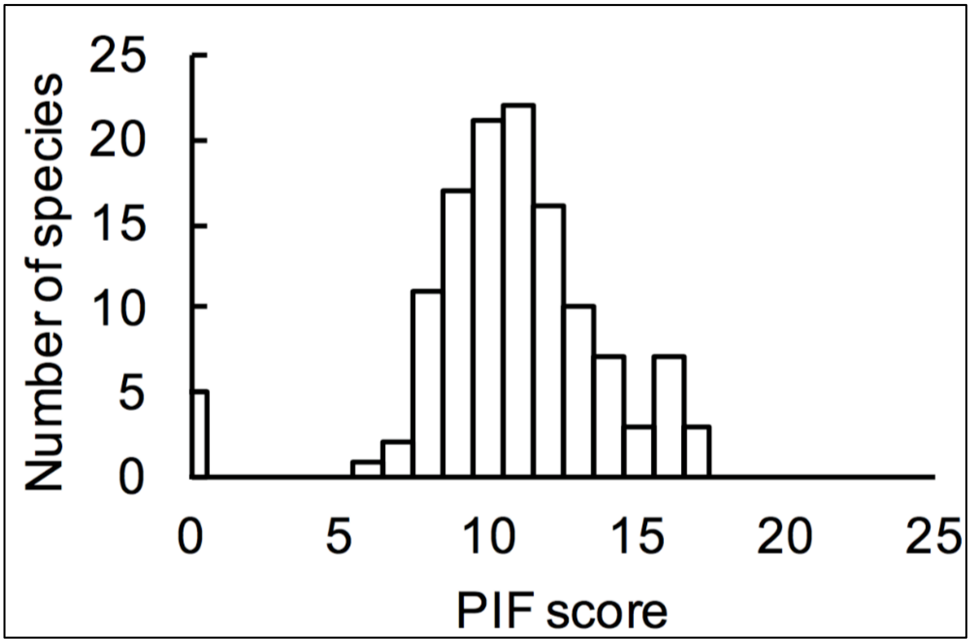

Figure 4.9.10. The distribution of Partners in Flight priority rankings for landbird species seen in 2015 within the Colorado portion of BCR18. The average ranking was 11.2 ± 0.2 out of a total possible score of 25. We assigned five non-native species a rank of zero. The lowest ranked native species was American robin with a score of six. The highest ranked native species were ferruginous hawk, lark bunting, and prairie falcon with scores of 17.

The BCR-wide average priority ranking for all landbirds known to occur is 11.24 (n = 194). In 2013, six landbird species for which PIF rankings were unavailable were reported within the BCR (blackpoll warbler, olive-sided flycatcher, orange-crowned warbler, rose-breasted grosbeak, white-crowned sparrow, and Wilson's warbler). In 2014, eight landbird species for which PIF rankings were unavailable were reported within the BCR (clay-colored sparrow, Lincoln's sparrow, olive-sided flycatcher, rose-breasted grosbeak, Swainson's thrush, veery, white-crowned sparrow, and Wilson's warbler). In 2015, eight landbird species for which PIF rankings were unavailable were reported within the BCR (clay-colored sparrow, Lincoln's sparrow, MacGillivray's warbler, northern goshawk, orange-crowned warbler, ruby-crowned kinglet, Swainson's thrush, and white-crowned sparrow).

While conservation values at Agate Fossil Beds NM were similar to those of the BCR in which the park is situated, reference criteria were unavailable to identify what conservation values constituted good or bad condition. Condition for conservation value was *Not Available.*

Confidence

Species abundance and occupancy were obtained from high-quality estimates from three years of monitoring data from up to 97 locations within the park. Partners in Flight priority rankings are reviewed periodically and are based upon the best available data and expert opinion. The confidence for both of these data sources was *High.*

Trend

Partners in Flight priority rankings may be updated periodically, but are not designed as a measure for assessing trend in risk. Occupancy/density estimates are calculated annually, but there were too few years available at the time of this assessment to calculate a trend in these parameters.

Breeding Bird Overall Condition

We did not assign an overall breeding bird condition to birds at Agate Fossil Beds NM, due to a lack of clear or accepted standards for doing so (Table 4.9.4). It may be possible to assign a condition in the future with the eventual availability of trend data or with clearly defined goals for the bird community or individual species. The total score for overall landbird condition was *Not Available* for Agate Fossil Beds NM (Table 4.9.5).

Table 4.9.4. Breeding bird overall condition.

Indicators	Measures	Condition
Species diversity	• Species richness	◯
Species abundance	• Mean density	◯
Conservation value	• Mean priority ranking	◯
Overall condition for all indicators and measures		◯

Table 4.9.5. Summary of breeding bird indicators and measures.

Indicator	Measure	Condition	Confidence	Trend	Condition rationale
Species diversity	Species richness	Not available	High	Not available	Species richness from 2013–2015 was 18.46 species/km^2. The data were collected as part of a rigorously designed monitoring program, so confidence was *High* and trend was *Not Available*.
Species abundance	Mean density	Not available	High	Not available	Mean density from 2013–2015 was 8.22 birds/km2. The data were collected as part of a rigorously designed monitoring program, so confidence was High and trend was Not Available.
Conservation value	Mean priority ranking	Not available	High	Not available	The mean priority ranking from 2013–2015 was 11.1. The data were gathered from a rigorous assessment, so confidence was High and trend was Not Available.

Confidence

Confidence was *High* for all three indicators. The score for overall confidence was 100 points, which met the criteria for *High* confidence in overall bird condition.

Trend

Trend data were *Not Available* for any indicators, so overall trend for birds was *Not Available*. While trend data were unavailable for Agate Fossil Beds NM, the following section presents more general BCR trend data for high priority species and non-native species found in the park unit.

Top-ranked Priority Species

The top three priority species observed at Agate Fossil Beds NM in 2013–2015 were the lark bunting, grasshopper sparrow, and northern harrier. The grasshopper sparrow was the most abundant and widely distributed of these three species (Table 4.9.6). We present general trends for these priority species using BBS data.

Table 4.9.6. Occupancy and density estimates for the top-ranked priority species in Agate Fossil Beds NM in 2015. RCS-b is the PIF regional priority ranking, count is the number of individuals observed, Psi is the occupancy estimate, %CV is the coefficient of variation, D is the density estimate, and N is the estimated population size at Agate Fossil Beds.

Common name	RCS--b	Count	Psi	% CV	D	% CV	N
Lark bunting	17	18	0.22	62	1.73	68	21
Grasshopper sparrow	16	55	0.81	18	35.25	34	423
Northern harrier	16	2	0.28	96	0.19	76	2

Breeding Bird Survey results and analyses, including species trends by bird conservation regions, are available online (Sauer et al. 2014). These results include a yearly percentage change in abundance, credible intervals, and an annual index of relative abundance (the mean count of birds on a typical route in the region for a year). The following figures show changes in the relative abundance index since the start of BBS surveys in the region. The lark bunting and grasshopper sparrow have both experienced significant regional declines (Figures 4.9.11 and 4.9.12). The northern harrier is a data-deficient species in the shortgrass prairie, but is nevertheless also experiencing significant declines (Figure 4.9.13).

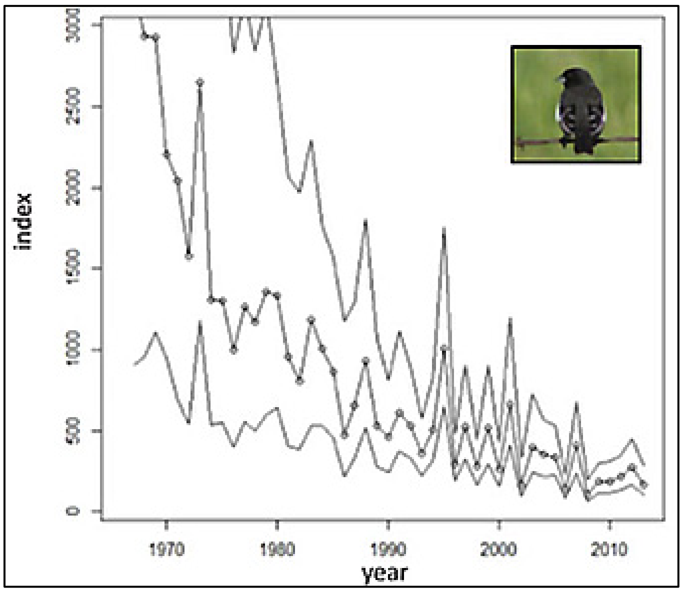

Figure 4.9.11. The lark bunting has experienced an average 6.2% (95% credible interval of −9.2 to −3.6) annual decrease in abundance within the shortgrass prairie bird conservation region from 1968 to 2013.

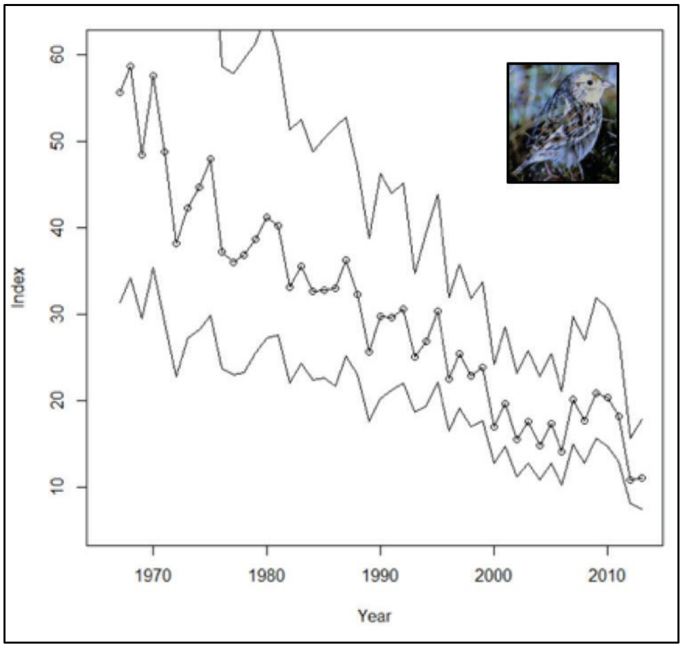

Figure 4.9.12. The grasshopper sparrow has experienced an average 3.4% (95% credible interval: −5.0 to −2.0) annual decline within the shortgrass prairie bird conservation region from 1968 to 2013.

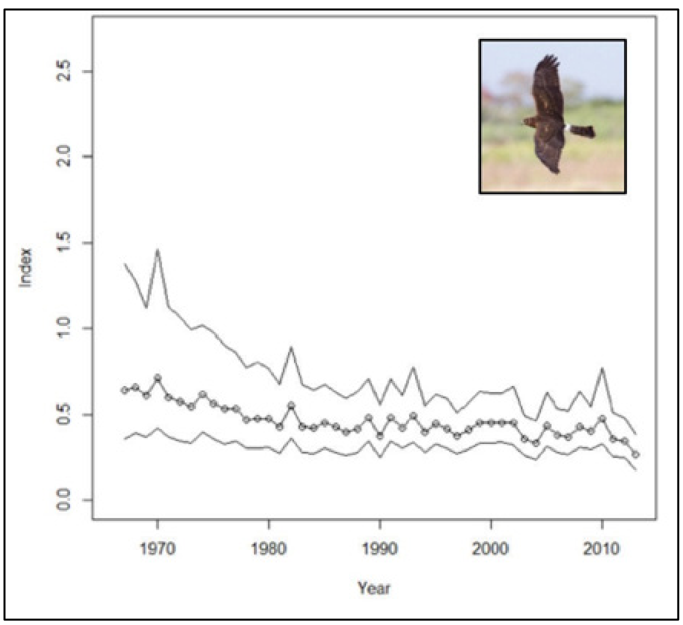

Figure 4.9.13. Northern harrier populations have likely been declining (-1.87% annual decrease, 95% credible interval: −3.79 to −0.32) within the shortgrass prairie bird conservation region from 1968 to 2013.

The regional trends presented below show all available data for each species within the shortgrass bird conservation region. The vertical axis represents the relative abundance index, with the point estimate indicated by a circle. The lark bunting has experienced an average 6.2% (95% credible interval of −9.2 to −3.6) annual decrease in abundance within the shortgrass prairie bird conservation region from 1968 to 2013 (Figure 4.9.11).

4.9.5. Stressors

Habitat loss and degradation are the primary causes of grassland bird declines (Peterjohn and Sauer 1995). The loss of native grasslands to agriculture, urban development, and forest regeneration amount to reductions in available habitat for grassland birds. Habitat degradation in the forms of fragmentation, grazing, fire, and intensive agricultural practices are additional factors that can cause declines in grassland bird populations.

Population declines in birds are, however, rarely attributable to any one cause. Mortalities and noise associated with roads can negatively impact bird populations (Kociolek et al. 2011). Climate change has been implicated in phenological and geographic distribution shifts of birds globally (Walther et al. 2002). West Nile virus has caused widespread declines of birds in North America in recent decades (LaDeau et al. 2007). The majority of bird species are migratory and populations likely experience other stressors on wintering grounds. Likewise, numerous threats to migration routes may largely be driven by changes occurring outside of parks (Berger et al. 2014).

The effects of introduced bird species on native species have not been well studied in the region. It is possible that these non-native species may compete with native species, possibly contribute to declines. However, it is also clear that some of these introduced species are declining themselves (Figure 4.9.14), perhaps due to the same causes of population decline in native species.

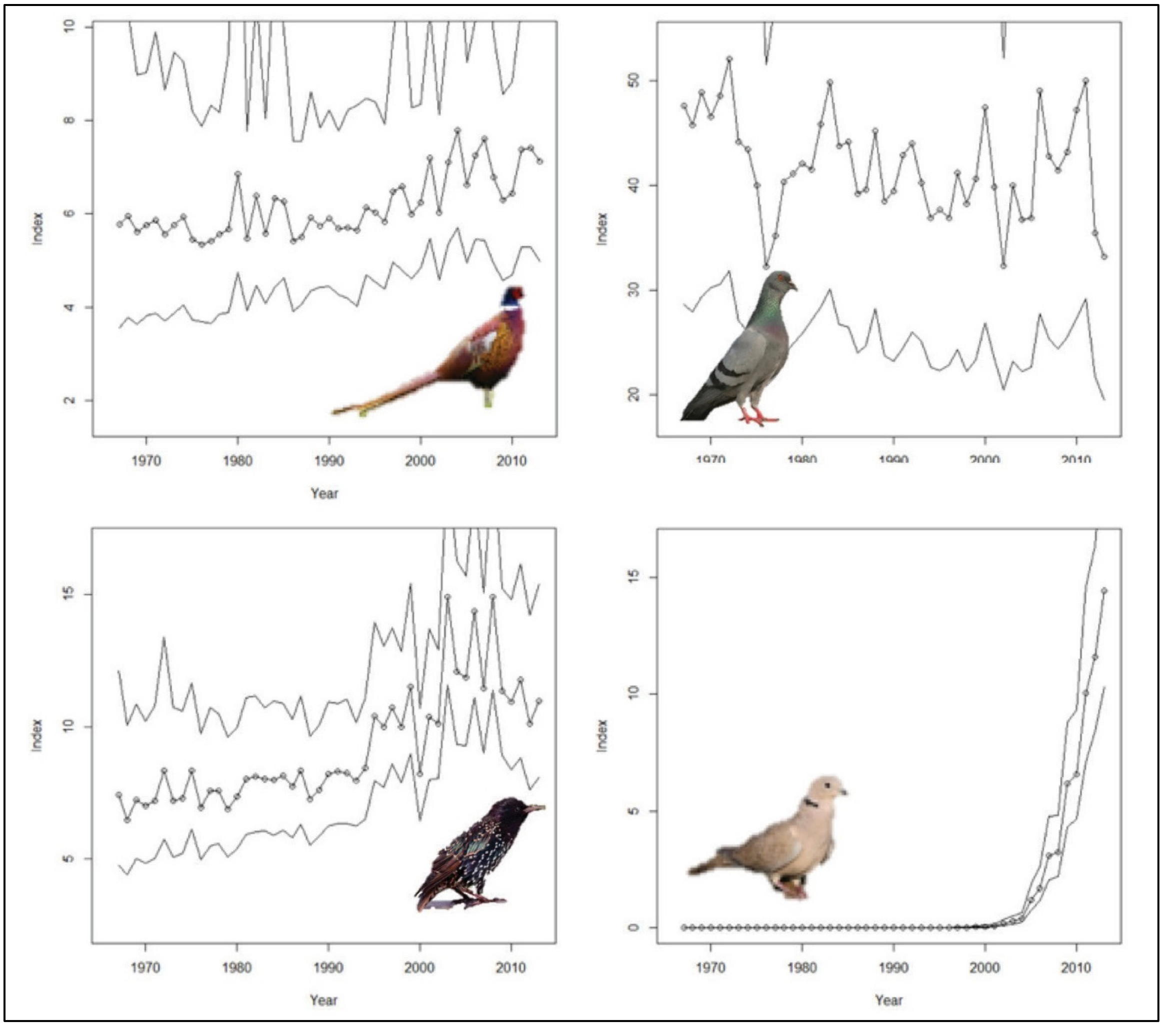

Figure 4.9.14. Region-wide trend data for four non-native species found at Agate Fossil Beds NM. From the top left: Ring-necked pheasant (PIF rank 14) and rock pigeon (PIF rank 8) populations have remained stable in the shortgrass region. European starling (PIF rank 8) populations have remained stable over the long-term, but may have been decreasing over the last decade. The Eurasian collared-dove (PIF rank 7) has increased significantly in the region.

4.9.6. Data Gaps

The IMBCR surveys were designed to be able to detect a three percent annual decline in occupancy or density over a period of 30 years, or the equivalent of a 60% population decline over the same time period (Beaupré et al. 2013). The greater the rate of change, the fewer years of monitoring data necessary to detect a decline or increase, although natural population fluctuations can obscure trends over short time scales. It will likely take at least 10 years of monitoring data before conclusions can be drawn about trends within individual parks.

Acknowledgments

- Adam Green (Bird Conservancy of the Rockies)
- Tim Nuttle (Civil and Environmental Consultants, Inc.)

- Tim O'Connell (Oklahoma State University)

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4.10. Fish

4.10.1. Background and Importance

Native fish in prairie rivers and streams have evolved in fluctuating environments, persisting through flooding events and hot, dry summers. While variable, these environments are somewhat predictable in their general flow regimes, and native species have biological strategies that allow them to adapt to changes within a natural historic range of variation (Dodds et al. 2004, McManamay et al. 2015).

National Park Service lands are important reference and monitoring sites for fish populations, though the rivers and streams that host these fish usually have a much smaller proportion of their total area within national parks than outside of park boundaries.

Regional Context

Prairie streams and rivers in the Great Plains are at a great risk to loss and alteration (Dodds et al. 2004, Perkin et al. 2015). The Niobrara River in Nebraska has changed in flow regime as a result of damming, particularly at Box Butte Dam, approximately 40 miles downstream of Agate Fossil Beds NM.

The native fish community at Agate Fossil Beds NM appears to have been largely extirpated in recent decades (Spurgeon et al. 2014). The latest survey of fish at Agate Fossil Beds NM detected only one species thought to occur naturally within the park, the white sucker (Figure 4.10.1).

Figure 4.10.1. The white sucker (*Catostomus commersoni*) is a native fish that can be found at Agate Fossil Beds NM (NPS photo).

One native species, the plains topminnow, is found primarily in Nebraska and is declining within Nebraska and throughout its range (Schneider et al. 2011, Pasbrig et al. 2012).

4.10.2. Fish Standards

While several fish species in Nebraska are under petition for federal protection, none of these were found in the Niobrara River at Agate Fossil Beds NM over the 37 years prior to this assessment. The plains topminnow (*Fundulus sciadicus*) is designated a Nebraska Tier I at-risk species, because it is both endemic and declining (Schneider et al. 2011). This species was detected within the bounds of Agate Fossil Beds NM in 1989, but has not been detected since (Spurgeon et al. 2014).

White sucker (*Catostomus commersoni*) may be exploited commercially in Nebraska (Nebraska Administrative Code Title 163, Ch. 2, 002.08), but bait harvest is closed in Niobrara River within Agate Fossil Beds NM and all tributaries west of Highway 385 (009.04A6).

4.10.3. Methods

<u>Indicators and Measures</u>

We assessed overall fish condition based on population growth and the composition of the fish assemblage.

Indicator: Population Growth

Tracking population size is an ideal unit for tracking how the health of a species changes.

<u>Measure of Population Growth: Population Growth Rate (λ)</u>

One basic way to measure the health of a species is to monitor how the numbers of individuals change over time. A population, a group of individuals of the same species that interact with each other, is an ideal unit for tracking these changes. Population growth rate (lambda or λ) for fish should be calculated over discrete time intervals to include new offspring. When $\lambda=1$, the population is stable, with no increases or decreases per year. If $\lambda=1.1$, the population has experienced a 10% increase per year, and if $\lambda=0.9$ then the population has experienced a 10% decline each year.

Increases in population size ($\lambda > 1$) usually indicate that the population is healthy and sufficient resources exist to support growth. We assigned the condition, *Resource in Good Condition* when a population was increasing (Table 4.10.1). A relatively stable number of individuals ($\lambda=1$) can also indicate a healthy population that fluctuates around a maximum capacity; unchanging population size also received the condition, *Resource in Good Condition*. Populations with declining numbers ($\lambda < 1$) are usually not in good condition; we assigned the condition, *Warrants Significant Concern* in this case. We did not assign the condition, *Warrants Moderate Concern*, to any value of growth rate.

Table 4.10.1. Fish community condition categories for growth rate.

Resource condition		
Condition Icon Definition	**Condition Icon**	**Growth rate (λ)**
Warrants significant concern	🔴	< 1
Warrants moderate concern	🟡	NA
Resource in good condition	🟢	≥ 1

While two years of data can give a growth rate, lambda (λ) is best calculated based on a minimum of three years; annual variance in resource availability and random differences in birth and death rates change λ from year-to-year. Confidence in the overall growth estimate increases with additional years of survey data.

Indicator: Community Composition

The composition of fish species present can indicate changes from historic conditions. While population sizes can fluctuate with environmental conditions, the overall species composition should remain similar over time.

Measure of Community Composition: Ratio of Native to Non-Native Fish Species

To identify changes in species composition, we compared the ratio of native species to non-native species over time. Stream condition was historically in good condition, so we used data collected in 1979 and 1989 as reference points against which to compare more recent data. If the ratio of native fish to non-native fish was statistically similar to these historic data, we gave the condition of *Resource in Good Condition* (Table 4.10.2). If the ratio was significantly lower, we gave the condition *Warrants Significant Concern*.

Table 4.10.2. Fish community condition categories for community composition.

Resource condition		
Condition Icon Definition	**Condition Icon**	**Growth rate (λ)**
Warrants significant concern	🔴	Outside the range of natural variation
Resource in good condition	🟢	Within natural range of variation

Data Collection and Sources

For this assessment we used data compiled by Spurgeon and others and collected by Stasiak, Pegg, and Pope (Spurgeon et al. 2014).

Quantifying Fish Condition, Confidence, and Trend

Indicator Condition

To quantify fish condition, we identified indicators, measures, and condition categories based on the scientific literature, regulatory standards, and expert opinion. We deferred to data collected most recently and rigorously.

Indicator Confidence

Confidence ratings were based on data availability (number of years) and data quality (e.g., survey design, estimation techniques). We gave a rating of *High* confidence when surveys were conducted regularly, data were collected recently, and the data were collected methodically. For qualitative data, we assigned a *High* confidence if more than one source indicated a similar condition. We assigned a *Medium* confidence rating when surveys were not conducted regularly, data were not collected recently, or data collection was not repeatable or methodical. For qualitative data, we assigned *Medium* confidence if only one source indicated a condition. *Low* confidence was assigned when there were no reliable data sources to support the condition.

Indicator Trend

Potential trend categories were *Improving*, *Unchanging*, *or Deteriorating*. To assign a trend to population growth rate (λ) for any fish species, we required at least three years of abundance data for that species. If no data were available that met these monitoring requirements for a particular indicator, we indicated that trend was *Not Available* for that indicator.

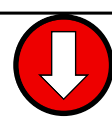
Overall Fish Condition, Confidence, and Trend

We used two indicators to assess condition of fish at Agate Fossil Beds NM. Overall condition depended on the average condition, confidence, and trend of those indicators.

4.10.4. Fish Conditions, Confidence, and Trends

Fish sampling occurred at two to six locations in 1979, 1989, 2008, and 2011. Seines were used in all years, and electrofishing was additionally used in 2008.

Growth Rate



Condition: Warrants Significant Concern
Confidence: High
Trend: Deteriorating

Condition

The abundance of all native fish surveyed declined from 1979 to 2011 (Figure 4.10.2). One non-native species, the northern pike, increased in abundance over this time period.

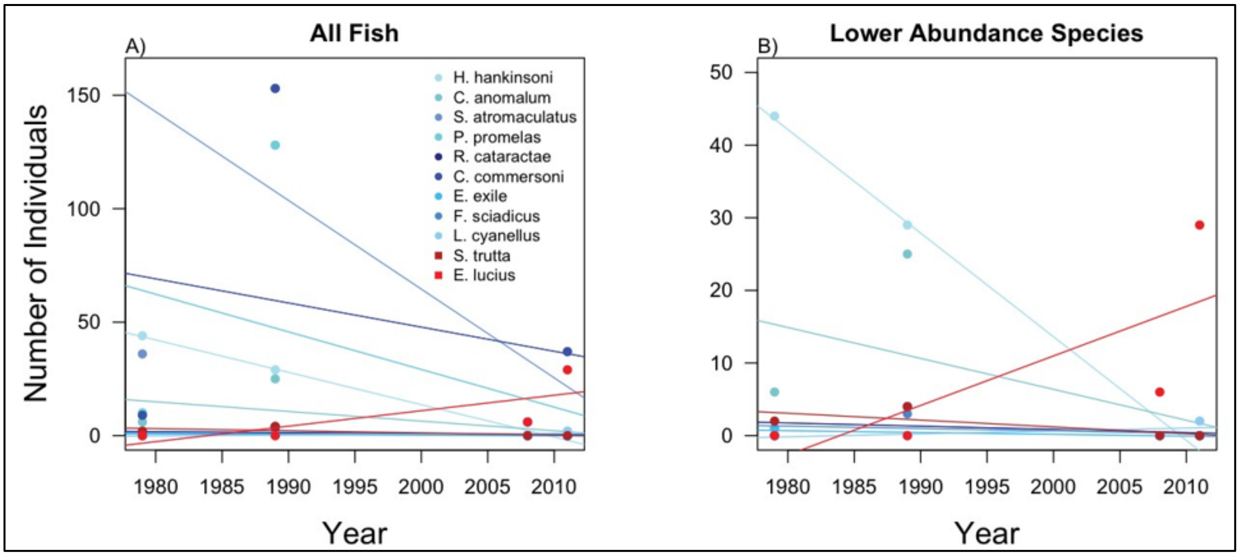


Figure 4.10.2. A) Changes in counts of all fish from surveys conducted in portions of Niobrara River located within Agate Fossil Beds National Monument and B) counts of fish with ≤ 50 individuals. Blue lines and points indicate native species and red lines and points indicate non-native species.

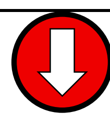
Confidence

Confidence was *High* due the relatively recent sampling (latest survey in 2011) and consistency of study methods across years.

Trend

Trend was *Deteriorating.*

<u>Community Composition</u>



Condition: Warrants Significant Concern
Confidence: High
Trend: Deteriorating

Condition

Eleven fish species were identified in the Niobrara River from 1979–2011 (Table 4.10.3). Eight of these species are native, but brown trout (*Salmo trutta*) are native to Europe. Green sunfish (*Leopmis cyanellus*) and northern pike (*Esox lucius*) are native to North America, but not to Agate Fossil Beds NM (Medley 2012). Five species of fish are suspected but unconfirmed at the park.

Table 4.10.3. Fish species identified in the Niobrara River from 1979–2011. List combined from Spurgeon et al. 2014 and NPSpecies.

Species name	Common name	Status in Agate Fossil Beds NM	Native to Nebraska	Native to Agate Fossil Beds NM	Status at Cherry Ranch
Hybognathus hankinsoni	Brassy minnow	Extirpated?	Yes	Yes	Present
Campostoma anomalum	Central stoneroller	Extirpated?	Yes	Yes	Present
Semotilus atromaculatus	Creek chub	Extirpated?	Yes	Yes	Present
Pimephales promelas	Fathead minnow	Extirpated?	Yes	Yes	Present
Rhinichthys cataractae	Longnose dace	Extirpated?	Yes	Yes	Present
Catostomus commersoni	White sucker	Probably present	Yes	Yes	Present
Etheostoma exile	Iowa darter	Extirpated?	Yes	Yes	–
Fundulus sciadicus	Plains topminnow	Extirpated?	Yes	Yes	Present
Salmo trutta	Brown trout	Extirpated?	No	No	–
Esox lucius	Northern pike	Probably present	No	No	–
Lepomis cyanellus	Green sunfish	Probably present	Yes	No	–
Notropis stramineus	Sand shiner	Unconfirmed	Yes	?	–
Phoxinus eos	Northern redbelly dace	Unconfirmed	Yes	?	–
Platygobio gracilis	Flathead chub	Unconfirmed	Yes	?	–
Ameiurus melas	Black bullhead	Unconfirmed	Yes	?	–
Hybognathus placitus	Plains minnow	Unconfirmed	Yes	?	–
Chrosomus neogaeus	Finescale dace	Unconfirmed	Yes	?	Present
Margariscus nachtriebi	Northern pearl dace	Unconfirmed	Yes	?	Present

Fish surveys conducted in 1979 and 1989 indicated that the Niobrara River a high quality community of native fish (Spurgeon et al. 2014) and that the community had changed very little over 10 years. However, surveys in 2008 and 2011 revealed a loss of native fishes and the increasing dominance of northern pike. The ratio of native to non-native fish species dropped to 0.5 in 2011 from a high of 7 in 1989 (Figure 4.10.3).

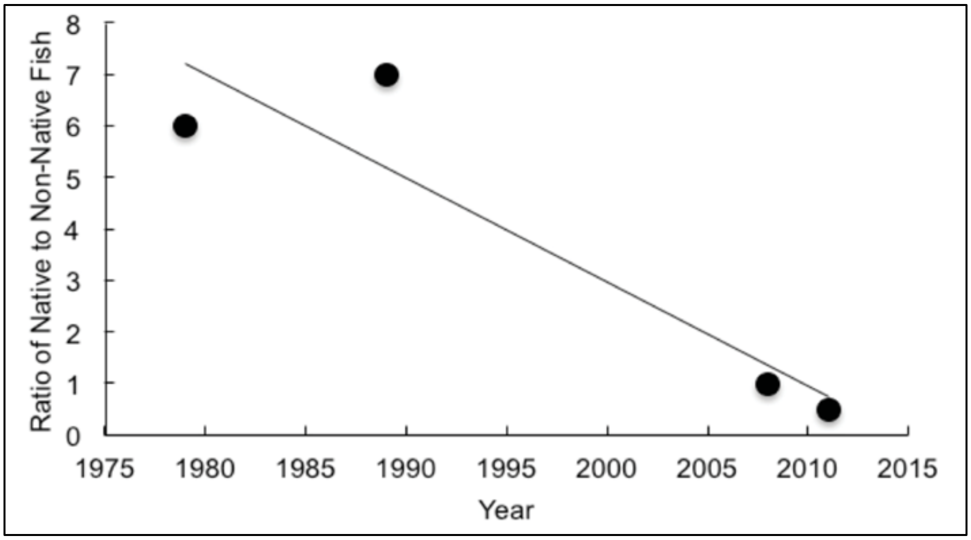


Figure 4.10.3. Change in the ratio of native to non-native fish from 1979–2011.

Confidence

Confidence was *High* due the relatively recent sampling (latest survey in 2011) and consistency of study methods across years.

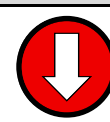
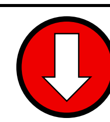
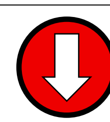
Trend

Trend was *Deteriorating*.

Fish Overall Condition

The average condition was 0 points, which indicates *Warrants Significant Concern* (Table 4.10.4). Confidence in the condition was *High*, and the overall trend was *Deteriorating*.

Table 4.10.4. Fish overall condition.

Indicators	Measures	Condition
Population growth	Growth rate	
Community composition	Ratio of native to non-native fish species	
Overall condition for all indicators and measures		

4.10.5. Stressors

Chemical Poisoning and Introduced Plant Species

There are multiple potential causes for the fish decline (Medley 2012): low dissolved oxygen due to decomposition of "excessive" floodplain vegetation—mostly the invasive yellow iris (*Iris pseudocorus*) (Figure 4.10.4), predation by invasive nonnative northern pike (*Esox lucius*), and habitat degradation. Chemical poisoning was a potential explanation for the extirpation of native fish in Agate Fossil Beds NM (Medley 2012), though herbicide had not been applied to vegetation near the water in the park prior to 2015 (B. Hauk, personal communication, 2 December 2016) and was therefore unlikely to have caused the decline in native fish species from 1989–2011. Poisoning from toxins produced by the invasive yellow iris is possible, but had not been confirmed in water samples at the time of this assessment. Medley suggested the removal of yellow iris.

Figure 4.10.4. Non-native yellow iris may be influencing water quality for fish at Agate Fossil Beds National Monument (Photo by Patrickdf, Wikipedia).

While chemical contamination by the iris is a current topic of inquiry (Medley 2012), the iris has definitely had a detrimental effect on aquatic ecology of the Niobrara in Agate Fossil Beds NM. Yellow flag iris, which has heavily invaded the banks of the river (Spurgeon et al. 2014, Tronstad 2015), accounted for > 10% of total cover and 14% of riparian cover (Prowatzke and Wilson 2015) in the park. Decomposing iris probably decreases DO, especially in the winter when the plants die back, and DO could also decrease when the river overflows into the floodplain (L. Tronstad, personal communication, 27 April 2016). Additionally, the iris may contribute to a narrowing of the channel, as well as slowing the flow rate (L. Tronstad, personal communication, 27 April 2016); the effect of these changes could include increased sedimentation and higher temperature. Chemical and physical changes to the stream caused by the iris likely affect fish, as they affect macroinvertebrate community composition (see section 4.5. Water Quality, of this NRCA for more details).

<u>Introduced Fish Species</u>

Introduced fish species have the potential to competitively interact with native fishes. The western mosquitofish (*Gambusia affinis*), while not yet detected at Agate Fossil Beds NM, competes with and may exclude the plains topminnow in nearby areas (Haas 2005, Schumann 2012). This species was found to associate positively with native fish assemblages, and be negatively impacted by introduced fish species (Fischer and Paukert 2008). Spurgeon et al. (2014) suggested that pike may be largely to blame for the extirpation of native fishes. Medley (2012) posited that introduced northern pike (*Esox lucius*) may lower native fish abundance, but are likely not responsible for the extirpation of native fish at Agate Fossil Beds NM. Nevertheless, Medley (2012) suggested, as one of many management actions, the mechanical removal and promotion of harvest of northern pike to reduce impacts from the non-native in the Niobrara River within Agate Fossil Beds NM.

4.10.6. Data Gaps

The presence and levels of pollution from herbicides, pesticides, grazing, and phytoxins (possibly from yellow iris) in the water are poorly understood.

<u>Acknowledgments</u>

- Darren Thornbrugh (NPS)
- Brennan Hauk (NPS)

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4.11. Invertebrate Pollinators

4.11.1. Background and Importance

Pollinators, animals that assist in the reproduction of plants, include a diverse group of organisms globally, from invertebrates to reptiles (Olesen and Valido 2003) to mammals (Fleming et al. 2001) and birds. The diversity and richness of pollinators have declined since the mid-20th century, and some species have disappeared altogether. This massive decline in pollinator health is attributable to a combination of disease, pesticides, and habitat loss (Goulson et al. 2015a). In North America, the decline in invertebrate pollinators in particular is likely to have extensive consequences for native plants (Potts et al. 2010, Thomann et al. 2013) and agriculture (NRC and NAP 2007). Invertebrate pollinators are found in many groups, including ants, beetles, birds, flies, butterflies, bees, and wasps.

The regal fritillary butterfly, a species of concern, is present in the park (Photo from Wikimedia Commons, 2008).

Declines in populations of European honey bees (*Apis mellifera*) have received much attention due to their role in agricultural production, but losses have been observed in wild (native) pollinators too (NRC and NAP 2007). With the exception of a few wild bees and butterflies, however, population data are scare for these unmanaged invertebrate species (NRC and NAP 2007). Even so, declines in many wild pollinator species are unfortunately obvious (Goulson et al. 2015b). Nearly 3,000 bee species are native to North America and about 40 of these bees are bumble bees—important pollinators of native plants (Koch et al. 2012). Losses to these bees could have extensive, cascading effects on ecosystems. A coordinated national monitoring effort would be the first step to understanding population trends and consequences of population changes in native invertebrate pollinators (Pollinator Health Task Force 2015).

National Park Service lands are critical reference and monitoring sites for invertebrate pollinator populations. The NPS is dedicated to protecting pollinators and their habitat; pollinator studies have been a part of research programs at several national parks and pollinator education programs were growing at the time of this assessment (NPS 2016).

Regional Context

Invertebrate pollinators in Nebraska include native insects and honey bees, all of which have varying food and habitat needs (Xerces Society 2016a, 2016b). Agate Fossil Beds NM is home to a total of 19 confirmed butterfly species (Lawson 2004), and may be host to even more species. Pearl crescent (*Phyciodes tharos*) were found within the park (Figure 4.11.1A), as were red admirals (*Vanessa atalanta rubria*) (Figure 4.11.1B), and melissa blue butterflies (*Plebejus melissa*) (Lawson 2004, Figure 4.11.1C). While bumble bees (*Bombus* sp.) and other invertebrate pollinators are likely present (Koch et al. 2012) in Agate Fossil Beds NM, local census data are lacking for the park.

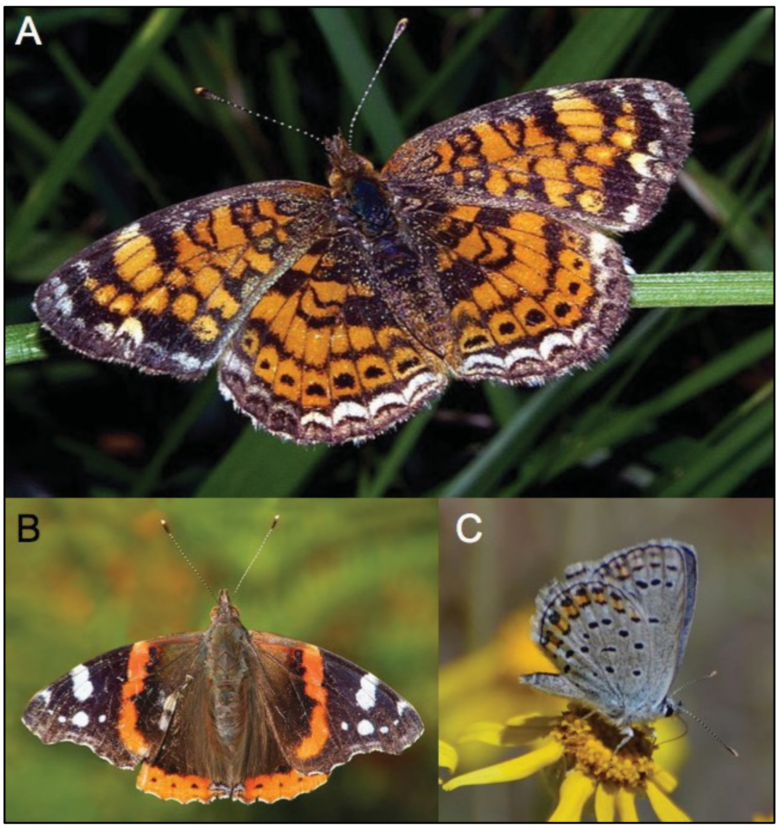


Figure 4.11.1. Butterfly species present at Agate Fossil Beds NM (Lawson 2004) include A) pearl crescent butterfly (*Phyciodes tharos*), B) red admirals (*Vanessa atalanta rubria*), C) and melissa blue butterflies (*Plebejus melissa*). Photos by K.D. Harrelson (2007), B. Kohl (2009), and A. Reago and C. McClarren (2014), respectively.

4.11.2. Invertebrate Pollinators Standards

Pollinator declines have captured national attention (Pollinator Health Task Force 2015), but national standards for the protection of pollinators are lacking. The EPA (2016) has proposed standards for pesticide toxicity levels to protect pollinators, but habitat protection guidelines only exist on a case-by-case basis for species currently listed in the Endangered Species Act (16 USC § 1531 et seq. 1973), if recovery plans have been completed. At the time of this assessment no invertebrate pollinators in Nebraska were listed species under ESA, though several species were being petitioned for ESA listing (USFWS 2016).

4.11.3. Methods

Indicators and Measures

We assessed invertebrate pollinator condition at Agate Fossil Beds NM based on three indicators: species diversity, species abundance, and status of vulnerable species. Each of these indicators contributes to different aspects of pollinator condition. We used measurements specified by the scientific literature and expert opinion. At the time of this assessment, no clear or accepted standard for assigning indicator conditions was available. In lieu of a full condition assessment we present potential indicators and measures, identify currently available data, and illustrate a framework that could be used to assess pollinator condition in the future. We focused on butterflies and bees here because the best available data pertain to these groups, but ideally other pollinator groups would be included in pollinator inventories and long term monitoring.

Indicator: Species Diversity

Quantifying biodiversity is a basic approach to assessing ecosystem condition. High diversity of species in a community can protect that community from disturbance (Tilman et al. 2006), promote productivity (Tilman et al. 1997), and preserve aspects of ecosystem function in variable environmental conditions (Brittain et al. 2013).

Measure of Species Diversity: Shannon Index

Species diversity is a combination of the number of species in a community and the proportional abundances of each of those species. A population approach to measuring diversity is to use Shannon's diversity index (H′), which quantifies a level of uncertainty (Shannon 1948). A higher value of H′ indicates a higher level of diversity. Expected diversity is likely to differ among habitat types; at the time of this assessment, no standard existed for expected level of diversity by ecosystem type.

Indicator: Species Abundance

Pollinator population abundance can change with alteration in land use (Foley et al. 2005, e.g., Potts et al. 2010) and consequent shifts in vegetation structure, competition, or predation pressures. This index is an important complement to diversity, as pollinator communities could have high diversity but at very low numbers. Further, different species may be affected unequally by land use change and other stressors, so monitoring the abundance of different pollinator species may be key to understanding the overall condition of a pollinator community.

Measure of Species Abundance: Pollinator Visitation Rate

Pollinator researchers frequently measuring pollinator abundance by visitation rate, to flowers, plants, or groups of plants (e.g., Utelli and Roy 2000). Observers record the number of invertebrates that visit flowers within a pre-determined sampling plot during a set period of time. Ideally, multiple observers collect data at different locations over the same time periods.

Measure of Species Abundance: Density in Pollinator Traps

Another approach to estimating pollinator abundance, and one that may require fewer person-hours in the short-term, is to deploy traps that capture pollinators. A variety of trapping methods can be successful, depending on the habitat (Lebuhn et al. 2013), but some methods may be biased towards certain taxa. With this potential bias in mind, several trapping approaches may be ideal. The trapping methods used should, at least, be standardized across sampling locations.

Indicator: Vulnerable Species

Like vertebrates and plants, invertebrate species can also receive special conservation status. Important pollinators on these lists may warrant extra protection from chemical spraying and habitat alteration.

Measure of Vulnerable Species: Level of Conservation Concern

Species of conservation concern are often given a special protection status or conservation priority by governing agencies. The highest level of legal protection for species in the U.S. is a listing under the Endangered Species Act (ESA), but other listings, such as the Xerces Society Red Lists (Xerces Society 2016a), indicate a level of concern for the species. This qualitative approach to assessing condition could enable managers to identify condition of various invertebrate pollinator groups through a simple census of species present at Agate Fossil Beds NP. The method for assign condition should be standardized across parks and could be separated by taxa or combined into an overall pollinator condition.

Data Collection and Sources

Data Management and Availability

For this assessment we used all available data, which included a butterfly census report (Lawson 2004) and Xerces Society Red Lists for native bees (Xerces Society 2016a) and butterflies and months (Xerces Society 2016b). We also searched museum records for specimens collected in Agate Fossil Beds NM.

Quantifying Pollinator Condition, Confidence, and Trend

Indicator Condition

To quantify invertebrate pollinator condition, we identified indicators, measures, and condition categories based on the scientific literature, regulatory standards, and expert opinion. We deferred to data collected most recently and most rigorously. Standards were unavailable for invertebrate pollinator condition, but when data and standards are available, managers can use a points system to assign each indicator to a category. This point system is based on the NPS methods that were developed to calculate overall air quality condition (NPS-ARD 2015), a methodical and rigorous assessment approach that can be applied to other resources as well. In this approach, we would assign zero points to the condition *Warrants Significant Concern*, 50 points to *Warrants Moderate Concern*, and 100 points to *Resource in Good Condition*. The average of all measures determines the condition category of the indicator; scores from 0–33 fall in the *Warrants Significant Concern* category, scores from 34–66 are in the *Warrants Moderate Concern* category, and scores from 67–100 indicate *Resource in Good Condition*.

Indicator Confidence

Confidence ratings were based on data availability (number of years) and data quality (e.g., survey design, estimation techniques). We assigned a rating of *High* confidence when surveys were conducted regularly, data were collected recently, and data were collected methodically. We assigned a *Medium* confidence rating when surveys were not conducted regularly, data were not collected recently, or data collection was not repeatable or methodical. *Low* confidence ratings were assigned when there were no good data sources to support the condition.

Indicator Trend

Potential trend categories were *Improving*, *Unchanging*, *or Deteriorating*. To assign a trend to diversity or abundance we required at least three years of data. If no data were available that met these monitoring requirements for a particular indicator, we indicated that trend was *Not Available* for that indicator.

Overall Pollinator Condition, Trend, and Confidence

If good quantitative data were available, we used the general approach for combining indicator conditions, trends, and confidence described in Chapter 3 (Methods 3.2.2) to calculate overall pollinator condition, trend, and confidence (Table 4.11.1). In the absence of adequate quantitative data, we assigned condition based on qualitative information, expert opinion, and consultation with NPS scientists.

Table 4.11.1. Summary of indicators and measures for invertebrate pollinators.

Indicator	Measure	Condition	Confidence	Trend	Condition rationale
Diversity	Shannon index (H')	Not available	Low	Not available	Data were unavailable and standards for assigning condition did not exist.
Abundance	Observed visitation rate	Not available	Low	Not available	Data were unavailable and standards for assigning condition did not exist.
	Mean density in traps	Not available	Low	Not available	Data were unavailable and standards for assigning condition did not exist.
Vulnerable species	Level of conservation concern	Warrants moderate concern	Low	Not available	Data were unavailable for species diversity and abundance; species of concern and species being considered for ESA listing could be present in the park.

4.11.4. Pollinator Conditions, Confidence, and Trends

Few data on pollinators were available for Agate Fossil Beds NM, though we were able to reference a butterfly census survey (Lawson 2004). Xerces Society Red Lists identified a number of species of concern in Nebraska and we were able to associate vulnerable status with a butterfly know to occur in Agate Fossil Beds NM, but only able to guess at the vulnerable bees likely to occur in the park.

Diversity

Condition: Not Available Confidence: Low Trend: Not Available

Condition

A butterfly species lists existed for Agate Fossil Beds NM (Lawson 2004), but no such list was available for other invertebrate pollinators. The butterfly survey involved a census of species present throughout the park. Sampling was conducted on five occasions between June–September 2004, and species indicated as present if observed (Lawson 2004). No museum records for invertebrate pollinators provided data beyond the scope of the 2004 inventory.

In the future, surveys of invertebrate pollinators at specified sampling locations, repeated on multiple occasions, and yielding abundance counts would provide a good start to measuring of overall pollinator diversity. Condition was *Not Available*.

Confidence

Few data existed for invertebrate pollinators at Agate Fossil Beds NM, and were collected for only one type of invertebrate pollinator. Confidence was *Low*.

Trend

Trend was *Not Available*.

Abundance

Condition: Not Available Confidence: Low Trend: Not Available

Condition

No pollinator abundance data were available for Agate Fossil Beds NM. Condition was *Not Available.*

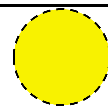
Confidence

No abundance data were available. Confidence was *Low*.

Trend

Trend was *Not Available*.

Vulnerable Species



Condition: Warrants Moderate Concern
Confidence: Low
Trend: Not Available

Condition

Regal fritillary (*Speyeria idalia*), a species of concern (Xerces Society 2016b) under petition for ESA listing, was identified as present at Agate Fossil Beds NM. Other butterflies in Nebraska were also species of concern, but not confirmed as present within the park; these species included arogos skipper (*Atrytone arogos*) and ottoe skipper (*Hesperia ottoe*), both of which the Xerces Society deems to be vulnerable species (Xerces Society 2016b). Monarch butterflies (*Danaus plexippus*) and western bumble bees (*Bombus occidentalis*), both under petition for ESA listing have ranges that overlap Agate Fossil Beds NM (Xerces Society 2016a), but had not been confirmed as present.

One pollinator of conservation concern was identified as present within Agate Fossil Beds NM and other species of concern were likely to be present as well. Condition was *Warrants Moderate Concern*.

Confidence

Few data existed for invertebrate pollinators at Agate Fossil Beds NM, and were collected for only one type of invertebrate pollinator. Confidence was *Low*.

Trend

Trend was *Not Available*.

Invertebrate Pollinators Overall Condition

Condition

Condition was unavailable for the diversity and abundance/ indicators due to a lack of reference standards and data (Table 4.11.2). One species of butterfly within the park was a species of conservation concern, and other species of concern could be present. Condition was *Warrants Moderate Concern* (Table 4.11.2).

Confidence

Few data existed for invertebrate pollinators at Agate Fossil Beds NM, and were collected for only one type of invertebrate pollinator. Confidence was *Low*.

Trend

Trend was *Not Available*.

Table 4.11.2. Invertebrate pollinators overall condition.

Indicators	Measures	Condition
Diversity	• Shannon index	
Abundance	• Mean visitation rate • Mean density in traps	
Vulnerable species	• Level of conservation concern	
Overall condition for all indicators and measures		

4.11.5. Stressors

Invertebrate pollinators are threatened globally and their decline could have major consequences for the health of many ecosystems, as well as commercial agriculture. In Nebraska, insecticide use, land conversion, and changes in climate could contribute to these declines. Many invertebrate pollinators rely on specific host plants, depositing their eggs so that larvae can feed on the plants before metamorphosing; protecting these plants is key to protecting specialized pollinators.

Agate Fossil Beds NM has the potential to be an important reference and monitoring site for pollinators; balancing the preservation of pollinators with other management goals, such as mosquito control, is a challenge to consider in the future.

4.11.6. Data Gaps

Butterfly data collected over 10 years prior to this assessment (Lawson 2004) and the Xerces Society Red Lists (Xerces Society 2016a, 2016b) formed the basis of our assessment. A comprehensive survey of all potential pollinators would be an important step to understanding condition of pollinators in Agate Fossil Beds NM, but monitoring should be designed so that methods can be consistent among NPS units (L. Tronstad, personal communication, 1 September 2016). Additionally, experts have yet to identify good measures of tolerance and susceptibility among invertebrate pollinates akin to those that exist for aquatic invertebrates (see Water Quality, Biological Indicators). Until such metrics are developed, pollinator researchers and managers may find some agreement about expected levels of diversity in various ecosystem types.

Acknowledgments

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Chapter 5. Discussion of Natural Resource Condition Assessment Findings and Considerations for Park Planning

5.1. Introduction

This chapter serves as a summary (Table 5.1) of natural resource conditions, potential threats and stressors to those resources, scientific needs and data gaps, and management issues for Agate Fossil Beds National Monument. The summaries and suggestions presented here were the result of a discussion among park managers, park administrators, and the authors of this assessment. In addition to the resource-specific summaries, this chapter contains details of overall concerns and pressing study needs for Agate Fossil Beds NM that would enable managers to maintain or improve resource conditions. Complete descriptions of each resource and detailed analyses are available in the individual natural resource sections.

Agate Fossil Hills (NPS photo).

Table 5.1. Summary of natural resources conditions, confidence, trends, and rationale for resource condition.

Priority resource	Condition, confidence, trend	Summary of overall condition
Viewshed		Viewshed condition was dependent on two indicators: scenic quality of view and land cover content within the viewshed. Three measures of scenic quality (landscape character integrity, vividness, and visual harmony) indicated good condition, as did a 95.5% natural land cover and 1.8% developed land cover. The likelihood of visual change to the Agate Fossil Beds NM viewshed was low to medium.
Night sky		NPS Natural Sounds and Night Skies Division collected night sky data in the park in 2006 and 2011. We used these data to assess night sky condition using two indicators: night sky quality and natural light environment. Three measures of night sky quality (Bortle dark sky index, synthetic sky quality meter, and sky quality index) indicated good condition, as did a low anthropogenic light ratio—the measure of natural light environment. Some light from the towns of Scottsbluff and Gering could affect the light environment some.

Table 5.1 (continued). Summary of natural resources conditions, confidence, trends, and rationale for resource condition.

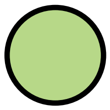
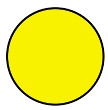
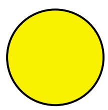
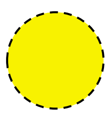
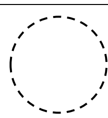
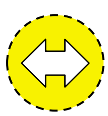
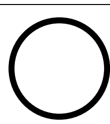
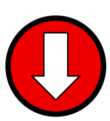
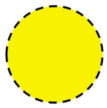
Priority resource	Condition, confidence, trend	Summary of overall condition
Soundscape		To assess soundscape conditions, we used data modeled by the Natural Sounds and Night Skies Division and a measure of impact identified by the division. A single indicator, anthropogenic impact, indicated that soundscape was in good condition. Potential stressors included vehicle traffic passing by the park on the main road, air traffic overhead, and cattle herding during certain times of year.
Air quality		Agate Fossil Beds NM is a Class II airshed and held to high air quality standards. Air quality indicators of ozone, visibility, nitrogen deposition, sulfur deposition, and mercury deposition indicated a condition of moderate concern for the park. Oil and gas development to the west of the park may be affecting air quality to some extent.
Surface water quality		We assessed water quality using the most recent data available for core water quality indicators (acidity, dissolved oxygen, temperature, specific conductivity) and biological indicators (invertebrate assemblage, fecal indicator bacteria). Core indicators were in a range of conditions, while aquatic invertebrates, generally reflective of more long term quality aspects, indicated significant concern; overall condition was moderate concern.
Geology		Exposed rock in the Fossil Hills provides an excellent example of the geology of the monument and the surrounding region. Recent rock falls, the major form of mass wasting that occurs at Agate, were behaving outside of the range of natural conditions. Though these events are natural, this departure from historical patterns was likely due to human activities and, therefore, of moderate concern.
Paleontological resources		Paleontological resource condition at the park was dependent on the potential for fossil loss. Data were unavailable for poaching and vandalism to fossils, so overall paleontological condition was likewise unavailable.
Vegetation		A complete vegetation assessment was completed for Agate Fossil Beds in the course of this NRCA and we based our assessment entirely on those results. Several measures of upland plant community and riparian plant community indicated moderate concern.
Birds		We presented a framework for assessing bird condition using species diversity, abundance, and conservation value, but at the time of this assessment no standards or consensus existed for evaluating condition of bird community. Condition was not available.
Fish		We assessed fish condition using two indicators: population growth rate of native species and community composition. Fish sampling occurred at two to six locations in 1979, 1989, 2008, and 2011, and the abundance of all native fish species declined over this time period. The ratio of native fish to non-native species also declined. Overall condition of fish was of significant concern.

Table 5.1 (continued). Summary of natural resources conditions, confidence, trends, and rationale for resource condition.

Priority resource	Condition, confidence, trend	Summary of overall condition
Pollinators		We presented a framework for assessing pollinator condition using species diversity, abundance, and vulnerability status, but at the time of this assessment no standards or consensus existed for evaluating condition of pollinator community. We used vulnerability status to assign a condition of moderate concern.

5.2. Connecting Natural Resource Condition Assessment Findings to Park Purpose and Significance

Natural resources Agate Fossil Beds NM contribute to the NPS Mission of preserving natural and cultural resources for future generations (NPS 2016) and are important for the protection of habitat and species within the region.

5.3. Resource Data Gaps and Management Issues

Several management themes emerged across natural resources. First, park staff discussed the need to continue systematic monitoring of natural resources. In conjunction with this research, park management emphasized the importance of integrating scientific information and management priorities into current and new education programs (J. Hill, personal communication, 27 September 2016). One recurring theme was the potential vulnerability of Agate Fossil Beds NM to land use changes and activities on adjacent lands, and the importance of staying informed of impending changes in the surrounding towns and counties that could affect park resources.

Also, the park shares some characteristics with Scott Bluff NM in that both are relatively small but have important natural resources. A recurring point that ran through our discussions with both Agate Fossil Beds NM and Scotts Bluff NM was that both parks would benefit from pooling funding resources to meet some needs that are not currently met. In particular, high erosion rates in portions of these parks lead to frequent exposure of fossils. To make these fossils available for public education and research, a paleontologist must keep pace with fossil discovery and collect, catalogue, and prepare specimens. This task is a challenging one, and leadership at Scotts Bluff NM and Agate Fossil Beds NM discussed how much both parks would benefit from sharing a paleontologist—an individual who would be fully devoted to these two parks. Further, developing some expertise in paleontology within park staff is a priority.

Additionally, native prairie grasslands have been so degraded across their historic range that very little intact habitat remains; remnant patches of native prairie are present within these parks and provide important habitat for grassland birds and other wildlife. Managers at both Agate Fossil Beds NM and Scotts Bluff NM felt that they would benefit from a shared biotechnician or vegetation specialist who could focus on these natural resources.

5.4. Resource Summaries and Management Issues

In addition to the management issues discussed above, we present resource-specific details on management concerns. For each resource we present a brief description of the context Agate Fossil Beds NM, summarize condition of the resource, and then describe data gaps and management issues. For full context, background, methods, and results, please consult the individual natural resource sections in Chapter 4.

5.4.1. Viewshed

At Agate Fossil Beds NM, exposed fossils, cultural landscapes, the Niobrara River, and views of western Nebraska are an important part of the visitor experience.

The landscapes in and around the park offer visitors an opportunity to enjoy a visual setting dominated by a largely intact and unaltered mixed grass prairie. This view is not unlike the one that the Cook family would have experienced when they settled next to the Niborara River in 1887, on land that is now part of Agate Fossil Beds NM. Tribes and early settlers would have likely seen mixed grassland prairie, once the dominant land cover in the region stretching for miles in all directions.

Despite the preserved prairie within Agate Fossil Beds NM, the landscapes of the region around the National Monument are now very different than they were in the late 1880s. Much of the prairie has since been converted to agriculture or developed for residential and industrial use. Many of the natural processes that helped shape the landscape, such as grazing by bison, are now absent or highly controlled. These changes in the surrounding landscape highlight the importance of the views that remain intact within Agate Fossil Beds NM.

Viewshed Condition Summary

Viewshed condition depended on two indicators: scenic quality of view and land cover content within viewshed. Three measures of scenic quality (landscape character integrity, vividness, and visual harmony) indicated good condition, as did a 95.5% natural land cover and 1.8% developed land cover. Viewshed condition was *Resource in Good Condition*, confidence in condition was *Medium*, and trend was *Not Available* (Table 5.1).

Viewshed Gaps and Management Issues

On-site monitoring and a full Visual Resource Inventory by the Air Resource Division would provide more detailed data than the remote sensing and modeling approach necessarily used here. Ongoing monitoring following this inventory is a high priority. Development outside of the park is a major concern, particularly with regard to development for oil, gas, and wind farms. Staying engaged in zoning and development process outside of the park is a high priority.

5.4.2. Night Sky

Clear, dark night skies are a valuable natural resource at Agate Fossil Beds NM. Park staff and residents are conscious of the valuable night sky resource and make an effort to keep Agate Fossil Beds NM as dark as possible at night. Some light pollution to the south, in Scottsbluff/Gering, can impinge on star gazing quality from the tops of hills or bluff; the best locations for stargazing are consequently in the valley where topographic features block most of the light. Stargazing programs are usually conducted in the fall, when the sun begins to set earlier. Rangers at Agate Fossil Beds NM lead these interpretive programs, guiding participants to identify sky objects and operate telescopes.

Night Sky Condition Summary

NPS Natural Sounds and Night Skies Division collected night sky data in the park in 2006 and 2011. We used these data to assess night sky condition using two indicators: night sky quality and natural light environment. Three measures of night sky quality (Bortle dark sky index, synthetic sky quality meter, and sky quality index) indicated good condition, as did a low anthropogenic light ratio—the measure of natural light environment. The greatest risk of light pollution is the community of Scottsbluff/Gering, about 45 miles to the south. Night sky condition was *Resource in Good Condition*, confidence in condition was *High*, and trend was *Not Available* (Table 5.1).

Night Sky Gaps and Management Issues

The most recent data were collected in 2008, and no subsequent sampling has been conducted since. Annual or biennial (every two years) sampling of night sky conditions at Agate Fossil Beds NM would improve the ability of managers to maintain optimal night sky conditions.

Working with neighbors to reduce light pollution is a high priority, especially regarding the process to receive Dark Skies certification. Neighbors > 50 miles away can affect the condition of the night skies at the park, but are far enough away to be disengaged. Education is also a high priority, and a focal point of the growing night sky program at Agate Fossil Beds NM.

5.4.3. Soundscape

Agate Fossil Beds NM is surrounded by vast areas of prairie, with some agricultural development along the Niobrara River upstream and downstream of the park.

Primary sources of non-natural sounds within the park include agricultural activities, automobile traffic on State Highway 29 and River Road, and air traffic passing overhead. Industrial activities and noise from business and heavily populated residential areas are unlikely to affect the acoustic environment in Agate Fossil Beds NM. The closest towns are Torrington, WY (population ~6,800), about 52 kilometers (32.5 miles) to the southwest of the park unit, and Mitchell, NE (population ~1,700), the same distance south of the park. The closest town with population > 10,000 is Scottsbluff, NE (population ~15,000), and 60 kilometers (37 miles) to the south.

Soundscape Condition Summary

To assess soundscape conditions, we used data modeled by the Natural Sounds and Night Skies Division (NSNSD) and a measure of impact identified by the division. A single indicator, anthropogenic impact, indicated that soundscape was in good condition. Potential stressors included vehicle traffic passing by the park on the main road, air traffic overhead, and cattle herding during certain times of year.

Soundscape condition was *Resource in Good Condition*, confidence in condition was *High*, and trend was *Not Available* (Table 5.1).

Soundscape Gaps and Management Issues

Regular, systematic monitoring of soundscape would be helpful for the park, particularly since seasonal changes in sound may not be captured in the modeled data. Management will request follow-up monitoring from NSNSD.

5.4.4. Air Quality

The American Lung Association compiles a State of the Air report for each state, and gives grades for air quality by county. Agate Fossil Beds NM is located in Sioux County where there were not enough monitoring data from 2013–2015 to assign a grade for ozone pollution or particle pollution; adjacent Scotts Bluff county, to the south, received a B (second best grade) for ozone during that time period, and an A (best grade) for short-term particle pollution. Three of Nebraska's 93 counties had sufficient data for the ALA to assign an overall grade to ozone pollution, and only six counties received a grade for particle pollution; the grades ranged from A to C, indicating heterogeneity in air quality.

Air Quality Condition Summary

Agate Fossil Beds NM is a Class II airshed and held to high air quality standards. Air quality indicators of ozone, visibility, nitrogen deposition, sulfur deposition, and mercury deposition indicated a condition of moderate concern for the park. Air quality condition was *Warrants Moderate Concern*, confidence in condition was *Medium*, and trend was *Not Available* (Table 5.1).

Air Quality Gaps and Management Issues

Oil and gas development to the west of the park may be affecting air quality to some extent. While current monitoring is sufficient to meet the needs of the park, managers will stay up to date on oil and gas development to head off potential consequences from new developments.

5.4.5. Water Quality

Agate Fossil Beds NM is located in northwest Nebraska on the Niobrara River in the Niobrara River Drainage (Middle North Platte-Scotts Bluff Watershed), which eventually flows east into the Missouri River. The Niobrara River is a prominent natural feature that bisects the park unit and is an important resource for agriculture, recreation, and plants and wildlife in the region. Approximately 280 milometers (174 miles) downstream of Agate Fossil Beds NM, the largely undisturbed Niobrara River is a designated National Scenic River under the Wild and Scenic Rivers Act for its unique natural and cultural resources. Protecting water quality in the Niobrara River at Agate Fossil Beds NM is a high regional priority for NPS.

Water Quality Condition Summary

We assessed water quality using the most recent data available for core water quality indicators (acidity, dissolved oxygen, temperature, specific conductivity) and biological indicators (invertebrate assemblage, fecal indicator bacteria). Core indicators were in a range of conditions, while aquatic invertebrates, generally reflective of more long term quality aspects, indicated significant concern. Overall water quality condition was *Warrants Moderate Concern*, confidence in condition was *Medium*, and trend was *Not Available* (Table 5.1).

Water Quality Gaps and Management Issues

Regular water quality monitoring in the park is a priority for managers at Agate Fossil Beds NM. The park will defer to NPS Inventory and Monitoring Program and Nebraska DEQ on the issue of water quality, but the overall condition is a concern. Staff at Agate Fossil Beds NM will focus on education, public outreach, and cooperation with neighbors upstream to spread awareness of these issues.

5.4.6. Geology

A major attraction at Agate Fossil Beds NM is the Fossil Hills, also known as Carnegie Hill. There are no current fossil collecting activities at Carnegie Hill, but visitors can see fossils collected at this quarry and others on display in the visitor center. At one time, exhibit cases were used to showcase in situ fossils at Carnegie Hill, but they were removed in the 1990s due to danger from rockfalls and vandalism.

Even without active fossil collection, the Fossil Hills are still an important geologic resource for Agate Fossil Beds NM as they are the area most identified with the park and are shown in many images of the monument. This cliff of exposed bedrock also provides an excellent example of the geology of the monument and the surrounding region and is, therefore, a valuable tool for interpretation of the geologic history of the area.

Geology Condition Summary

Exposed rock in the Fossil Hills provides an excellent example of the geology of the monument and the surrounding region.

Recent rock falls, the major form of mass wasting that occurs at Agate Fossil Beds NM, were behaving outside of the range of normal conditions. Though these events are natural, this departure from historical patterns was likely due to human activities. Geologic resource condition was *Warrants Moderate Concern*, confidence in condition was *Low*, and trend was *Not Available* (Table 5.1).

Geology Gaps and Management Issues

The lack of data on rates of weathering and erosion at Agate Fossil Beds NM is a major gap, as this information would allow better assessment of the vulnerability of fossils to degradation by weathering and erosion. Photographs of these sites would be particularly useful for monitoring. The major limitation to implementing a photo monitoring program is lack of personnel.

Park management identified a need to have a single geologist or paleontologist tied more closely with Scotts Bluff NM and Agate Fossil Beds NM. Leadership at both parks discussed how much both parks would benefit from sharing a paleontologist—an individual who would be fully devoted to these two parks.

5.4.7. Paleontological Resources

The fossil-bearing rocky outcroppings in Agate Fossil Beds NM, the Harrison Formation and the overlying “Anderson Ranch Formation” of the Arikaree Group, both contain abundant vertebrate fossils indicative of grasslands including: birds; perissodactyls such as rhinoceros, tapirs, and horses;

artiodactyls such as camels, oreodonts, and entelodonts ("hell pigs"); and carnivores such as early canids, bears, and mustelids. In addition, a unique trace fossil is well known from Agate Fossil Beds NM: the preserved burrow of the early beaver *Paleocastor*. The burrow itself is termed Daemonelix, "Devil's Corkscrew" and was initially thought to be the remnants of a cavity formed by a giant taproot.

Paleontological Resource Condition Summary

Paleontological resource condition at the park depended on the potential for fossil loss. Data were unavailable for poaching and vandalism to fossils, so overall paleontological condition was likewise *Not Available*. Confidence in condition was *Low*, and trend was *Not Available* (Table 5.1).

Paleontological Resource Gaps and Management Issues

Fossils are important natural resources at Agate Fossil Beds NM, and the park needs an efficient way to manage fossil recovery and curation (J. Hill, personal communication, 29 September 2016). A data gap is the lack of information on fossil poaching and vandalism. While several locations are potentially threatened by vandalism, no specific reports of vandalism exist. Photographs of these sites would be particularly useful for monitoring. The major limitation to implementing a photo monitoring program is lack of personnel.

Park management identified a need to have a single geologist or paleontologist tied more closely with Scotts Bluff NM and Agate Fossil Beds NM. Leadership at both parks discussed how much both parks would benefit from sharing a paleontologist—an individual who would be fully devoted to these two parks.

5.4.8. Vegetation

Excerpt taken from vegetation reports written by Isabel W. Ashton and Christopher J. Davis (2016):

> *Vegetation monitoring began in AGFO in 1998 by the Heartland Inventory & Monitoring Program (James 2010a) and the Northern Great Plains Fire Ecology Program. In 2010, AGFO was incorporated into the Northern Great Plains Inventory & Monitoring Network (NGPN). At this time, vegetation monitoring protocols and plot locations were shifted to better represent the entire monument and to coordinate efforts with the FireEP, and sampling efforts began in 2011. In 2012, the NGPN began monitoring an additional 17 plots within the riparian corridor to assess riparian condition. In this report, we use the data from 2011–2015 to assess the current condition of AGFO vegetation and the data from 1998–2015 are used to look at longer-term trends.*

Vegetation Condition Summary

A complete vegetation assessment was completed for Agate Fossil Beds in the course of this NRCA and we based our assessment entirely on those results. Several measures of upland plant community and riparian plant community indicated moderate concern. Overall vegetation condition *Warrants Moderate Concern*, confidence in condition was *Low*, and trend was *Unchanging* (Table 5.1).

Vegetation Gaps and Management Issues

Data were thorough, but considering the historical context of vegetation within the park is also very important. Management at Agate Fossil Beds NM agreed that obtaining a summary of environmental history of the park would be helpful for this context.

Additionally, the park would benefit from a close comparison of existing plant communities and historic composition of native prairie species curation. These goals are consistent with those discussed by managers at Scotts Bluff NM, and both parks agreed that they would benefit from sharing a biotechnician or ecologist to focus on these issues. A medium priority for the park is to create a vegetation management plan. A plan to reintroduce bison is also a possibility, with the particular aim of bison functioning as biological controls to maintain native prairie. A feasibility study has been developed for this potential plan; ecologically a bison reintroduction poses few risks to park goals, but the park would have to navigate challenges with infrastructure, protecting paleontological resources, funding, and expertise (Licht 2014). The discussion on this topic is ongoing.

5.4.9. Birds

Agate Fossil Beds NM is located within the shortgrass prairie bird conservation region (BCR). The shortgrass prairie is an arid region with limited vegetation height and diversity. Some of North America's highest priority birds breed here, including the grasshopper sparrow a species that is present at Agate Fossil Beds NM. Most grassland bird species are declining in North. While the overall trend for birds in the shortgrass BCR is stable, all of the grassland-obligate species there exhibit negative trends. The causes of declines in species such as the grasshopper sparrow are poorly understood but could be related to a reduction in the diversity of native herbivores, such as bison and prairie dogs that create high quality habitat for many grassland bird species.

Another source of important bird habitat within Agate Fossil Beds NM is the riparian area associated with the Niobrara River. Loss of riparian habitat is another major cause of bird declines regionally.

Bird Condition Summary

For species not formally protected by the Endangered Species Act, calculating bird condition is not straightforward. To calculate a condition score, we would have needed empirically derived estimates of the levels of species diversity, species abundance, and conservation values that revealed the condition of the species within the park unit. Those criteria are absent from the literature, and assigning a condition score without them would have been unwarranted. In lieu of condition scores, we presented values for indicators based on the best available data; natural resource managers can reference these values in current and future park planning.

We presented a framework for assessing bird condition using species diversity, abundance, and conservation value, but at the time of this assessment no standards or consensus existed for evaluating condition of bird community. Overall condition of birds was *Not Available*, confidence in condition was *High*, and trend was *Not Available* (Table 5.1).

Bird Gaps and Management Issues

To identify condition of birds in the park in the future, NPS will need to identify management goals. An ongoing natural history program could coordinate with the data collection to monitor species over time. Management emphasized that encouraging study by scientific institutions would be helpful in this regard (J. Hill, personal communication, 27 September 2016).

5.4.10. Fish

Prairie streams and rivers in the Great Plains are at a great risk to loss and alteration. The Niobrara River in Nebraska has changed in flow regime as a result of damming, particularly at Box Butte Dam, approximately 40 miles downstream of Agate Fossil Beds NM.

The native fish community at Agate Fossil Beds NM appears to have been largely extirpated in recent decades. In 2012, a technical assistance for northern pike removal and reintroduction of native fish was denied. The latest survey of fish at Agate Fossil Beds NM detected only one species thought to occur naturally within the park, the white sucker (*Catostomus commersoni*), down from eight native species detected in 1979 and 1989. One native species, the plains topminnow (*Fundulus sciadicus*) is found primarily in Nebraska and is declining within Nebraska throughout its range. The plains topminnow is designated a Nebraska Tier I at-risk species, because it is both endemic and declining. This species was detected within the bounds of Agate Fossil Beds NM in 1989, but has not been detected since.

Fish Gaps and Management Issues

While chemical contamination by the iris is a current topic of inquiry, the iris has definitely had a detrimental effect on aquatic ecology of the Niobrara in Agate Fossil Beds NM. Yellow flag iris, which has heavily invaded the banks of the river, accounted for > 10% of total cover and 14% of riparian cover in the park. Decomposing iris probably decreases DO, especially in the winter when the plants die back, and DO could also decrease when the river overflows into the floodplain). Additionally, the iris may contribute to a narrowing of the channel, as well as slowing the flow rate; the effect of these changes could include increased sedimentation and higher temperature. Chemical and physical changes to the stream caused by the iris likely affect fish, as they affect macroinvertebrate community composition—an indicator of water quality (see section 4.5. Water Quality, of this NRCA for more details).

Introduced fish species have the potential to competitively interact with native fishes. The western mosquitofish (*Gambusia affinis*), while not yet detected at Agate Fossil Beds NM, competes with and may exclude the plains topminnow in nearby areas. This species was found to associate positively with native fish assemblages, and be negatively impacted by introduced fish species.

Introduced northern pike (*Esox lucius*) may lower native fish abundance, but are likely not responsible for the extirpation of native fish at Agate Fossil Beds NM.

5.4.11. Pollinators

Invertebrate pollinators in Nebraska include native insects and honey bees, all of which have varying food and habitat needs. Agate Fossil Beds NM is home to a total of 19 confirmed butterfly species

(Lawson 2004), and may be host to even more species. Pearl crescent butterflies (*Phyciodes tharos*) were found within the park, as were red admirals (*Vanessa atalanta rubria*), and melissa blue butterflies (*Plebejus melissa*). While bumble bees (*Bombus* sp.) and other invertebrate pollinators are likely present in Agate Fossil Beds NM, local census data are lacking for the park.

Pollinators Condition Summary

We presented a framework for assessing pollinator condition using species diversity, abundance, and vulnerability status, but at the time of this assessment no standards or consensus existed for evaluating condition of pollinator community. We used vulnerability status to assign a condition of *Moderate Concern*. Confidence in condition was *Low* and trend was *Not Available* (Table 5.1).

Pollinators Gaps and Management Issues

Butterfly data collected over 10 years prior to this assessment and the Xerces Society Red Lists formed the basis of our assessment.

A comprehensive baseline inventory of all pollinators is key to understanding condition of pollinators in Agate Fossil Beds NM. Several bees and butterflies are under petition for listing under the Endangered Species Act; a baseline inventory of pollinators at the park would elucidate if those species are present or if they could be present in the park.

Following baseline inventory, monitoring protocols should be designed so that methods can be consistent among NPS units. This monitoring effort is an opportunity for Agate Fossil Beds NM to involve citizen science and build new connections with local universities. In particular, an education program centered on butterflies could be fruitful.

Appendix A. Viewshed details and figures for each vantage point included in the assessment

Table A1 shows the location of the seven vantage points. Figures A1 through A7 are the vantage point viewsheds.

Table A1. Digital viewshed analyses were completed for each of the seven following vantage points, but modified Visual Resource Inventories were only completed for the points designated with asterisks (*).

Vantage Point	Location	Figure
*AGFO Vantage 1 (Daemonelix Trail)	42.429751, −103.784905	Figure A1
AGFO Vantage 2	42.424857, −103.788804	Figure A2
*AGFO Vantage 3 (Visitor Center)	42.425242, −103.732722	Figure A3
AGFO Vantage 4	42.424557, −103.729405	Figure A4
AGFO Vantage 5	42.415711, −103.727603	Figure A5
AGFO Vantage 6	42.417521, −103.727639	Figure A6
*AGFO Vantage 7 (Fossil Hills)	42.416711, −103.728421	Figure A7

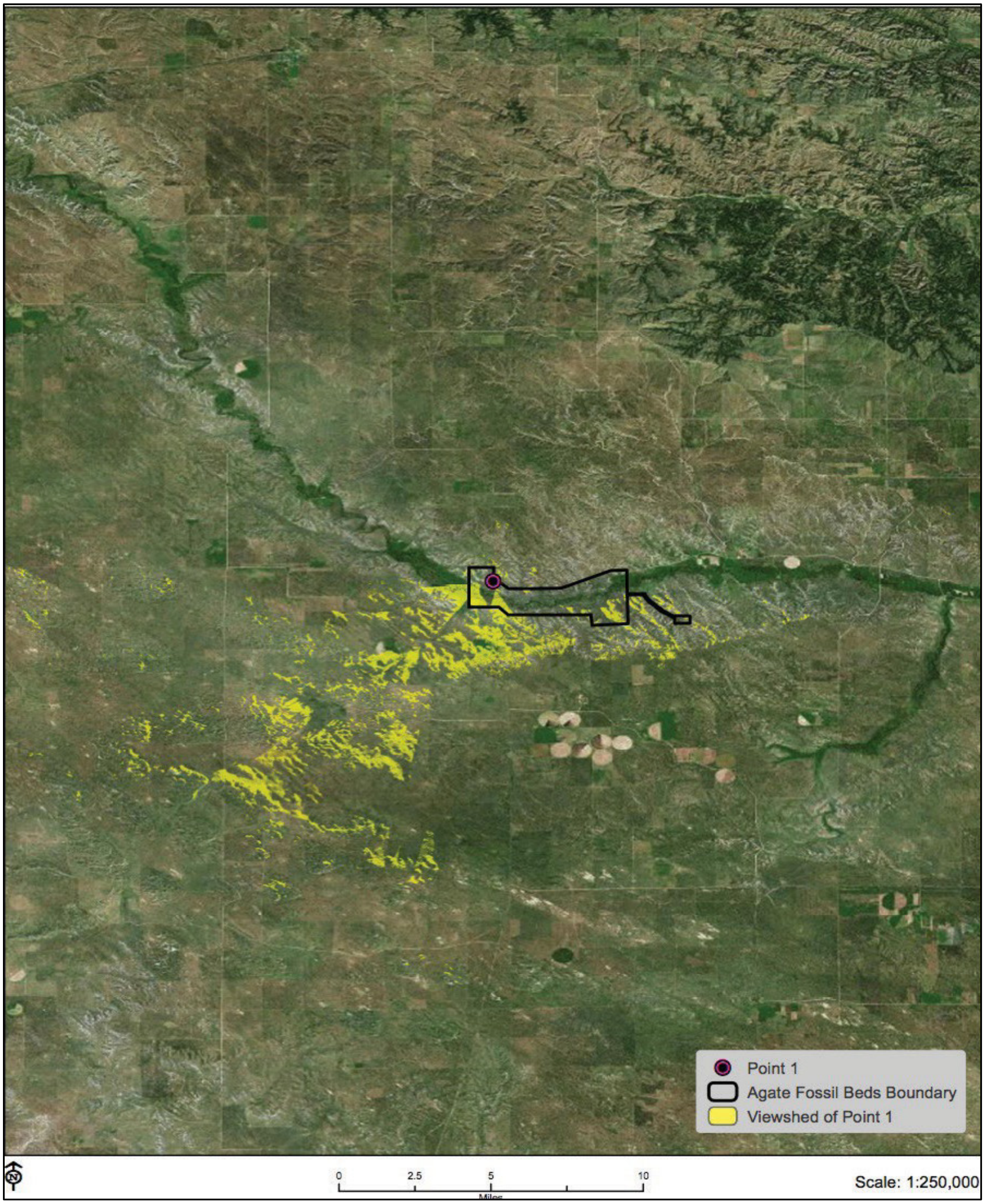


Figure A1. Viewshed for vantage point 1 in Agate Fossil Beds NM.

Figure A2. Viewshed for vantage point 2 in Agate Fossil Beds NM.

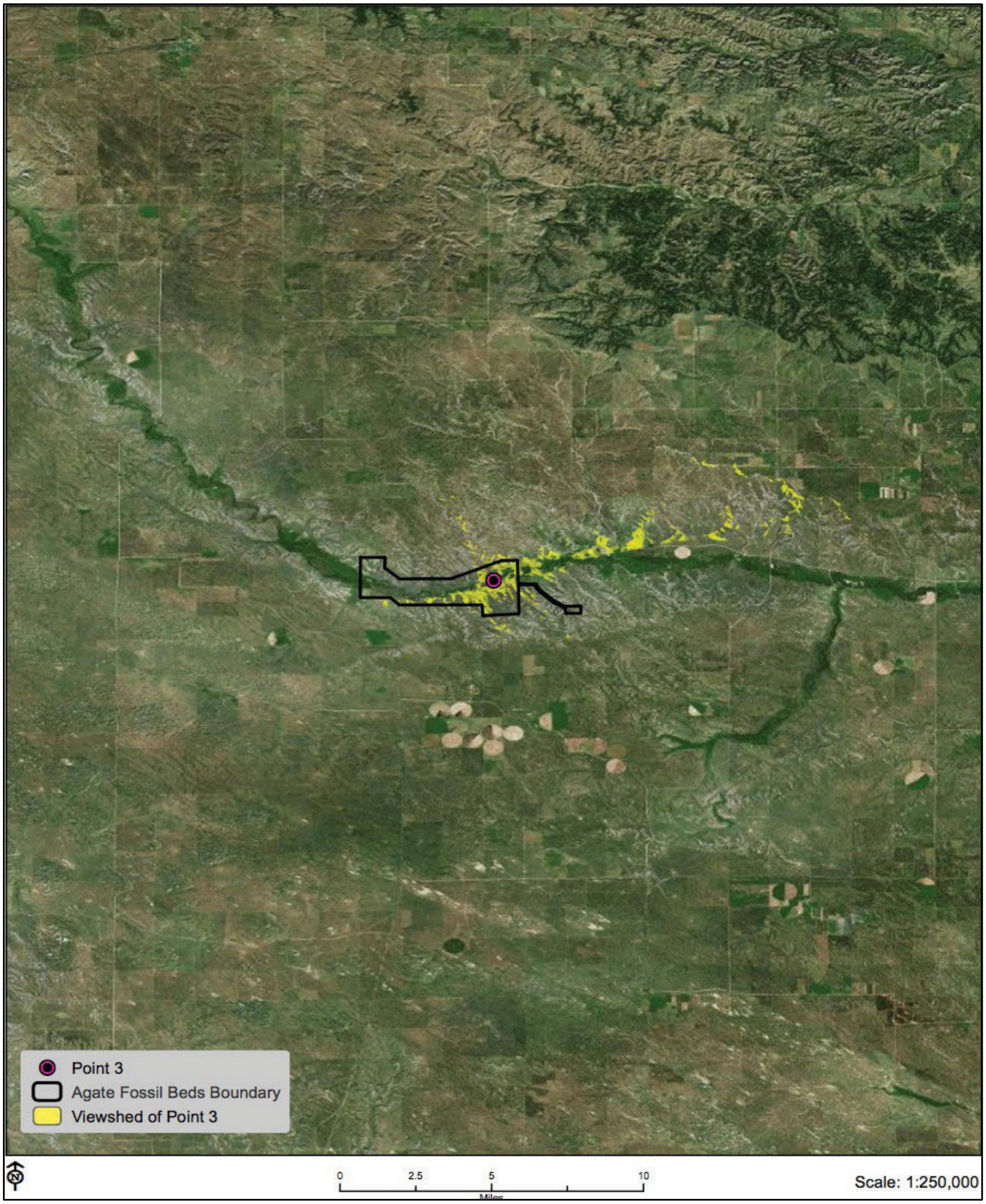


Figure A3. Viewshed for vantage point 3 in Agate Fossil Beds NM.

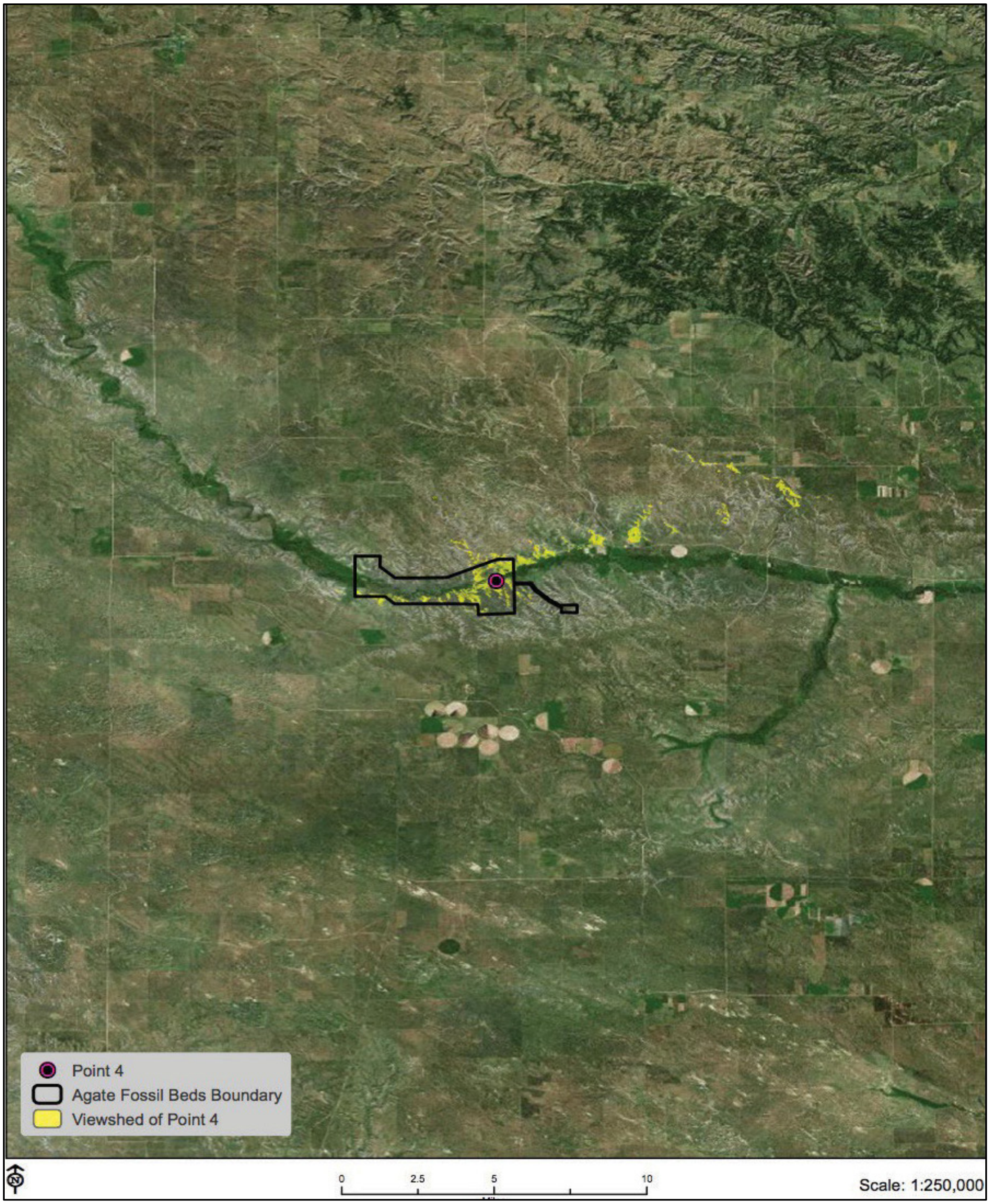


Figure A4. Viewshed for vantage point 4 in Agate Fossil Beds NM.

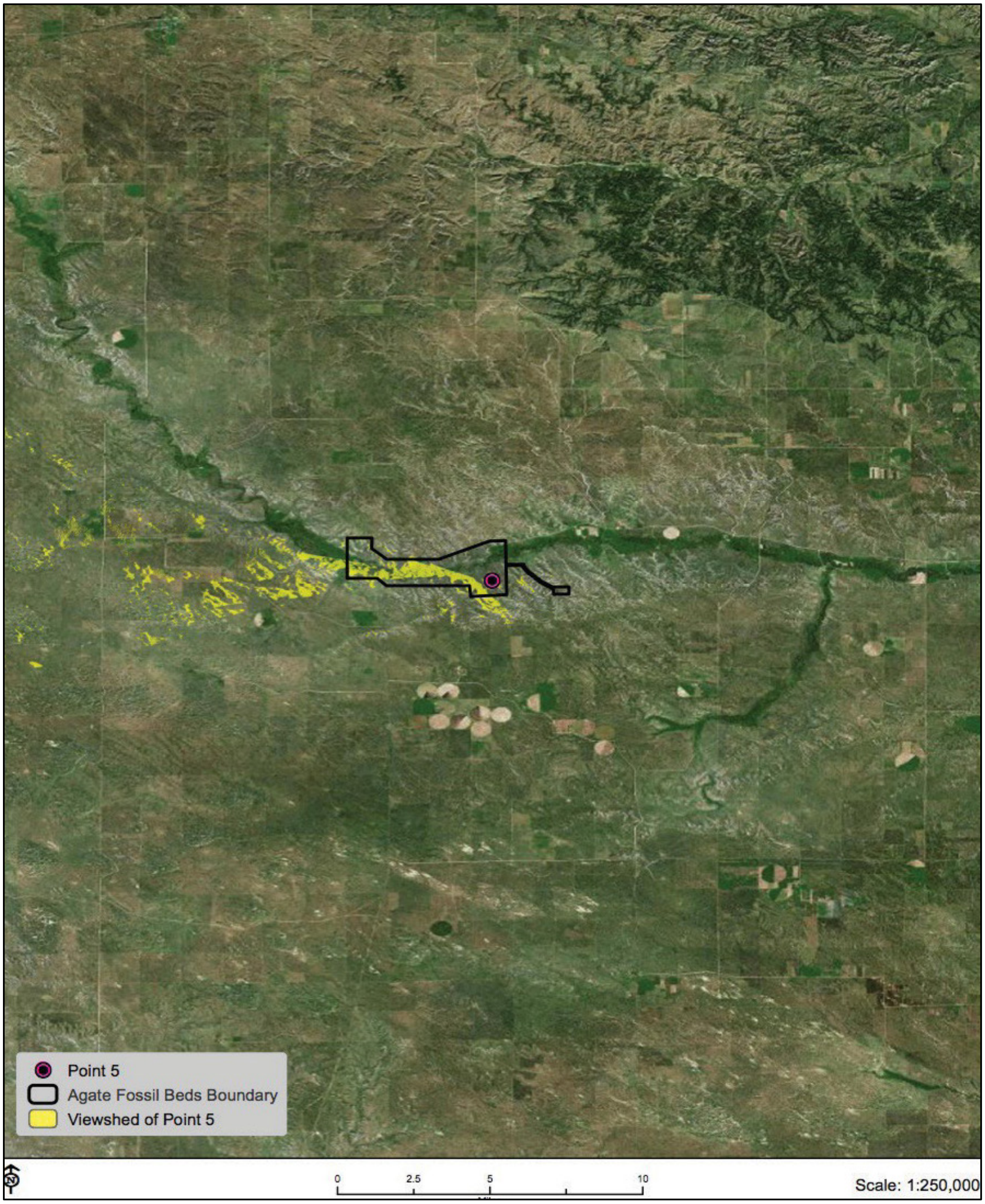


Figure A5. Viewshed for vantage point 5 in Agate Fossil Beds NM.

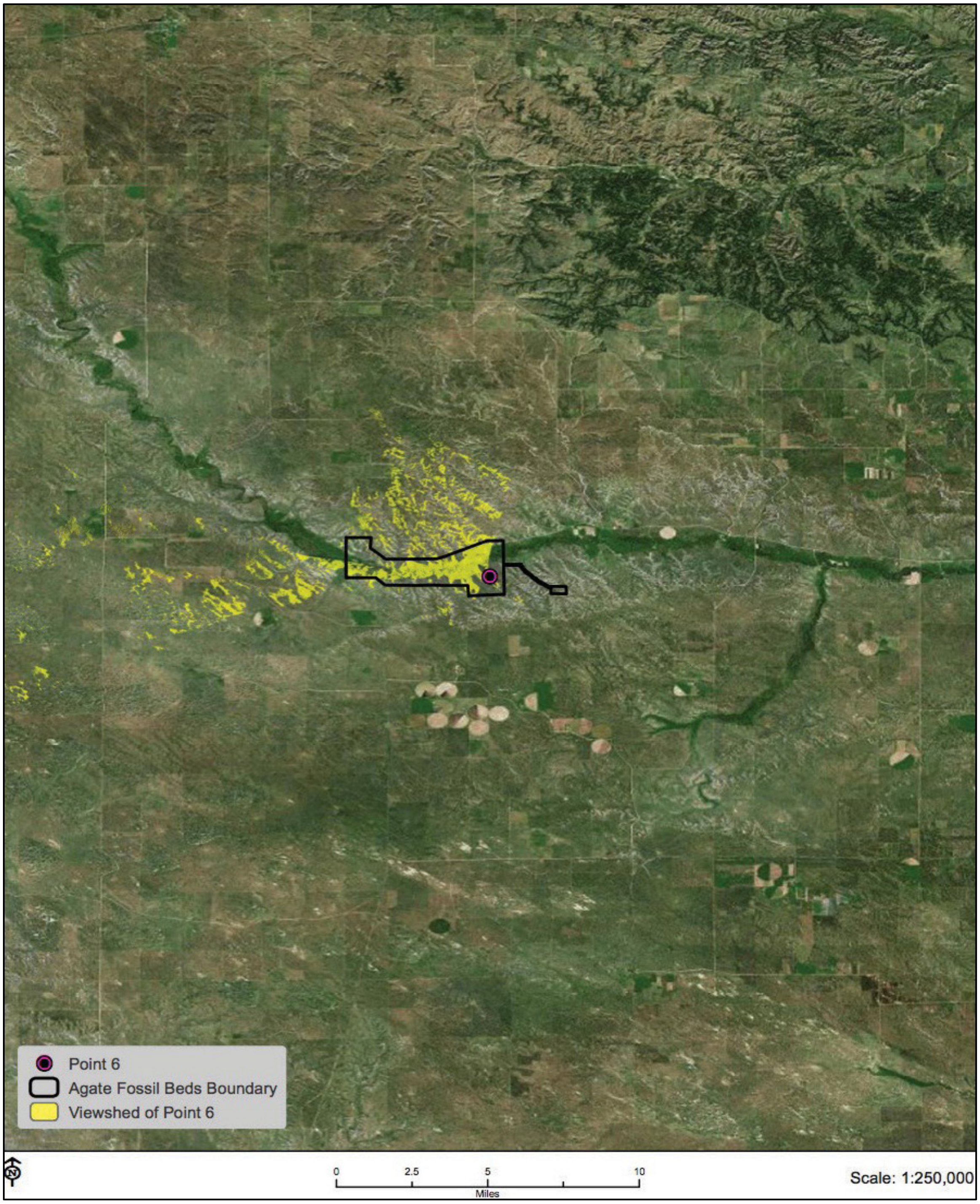


Figure A6. Viewshed for vantage point 6 in Agate Fossil Beds NM.

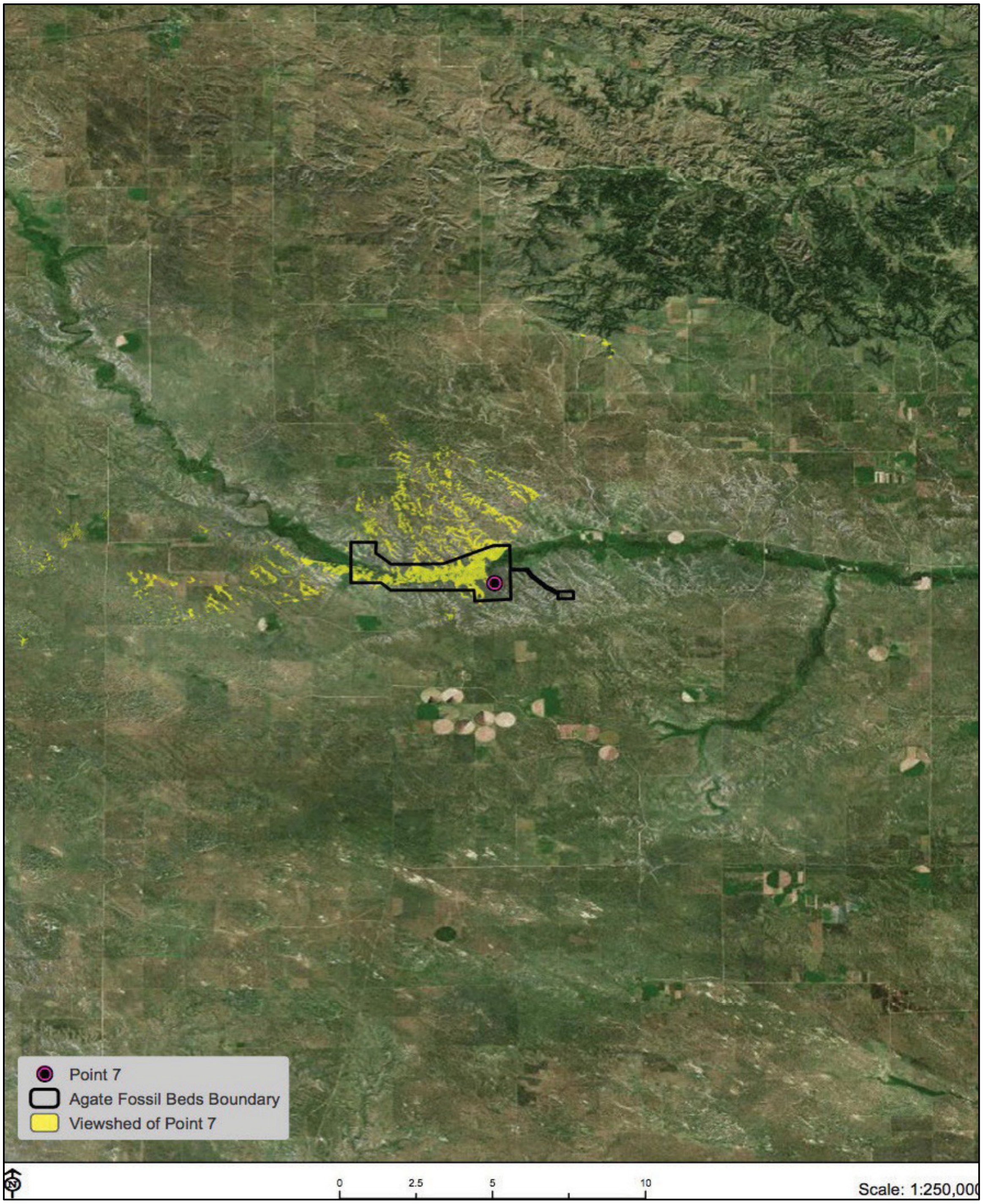


Figure A7. Viewshed for vantage point 7 in Agate Fossil Beds NM.

Appendix B. Methods for Viewshed Analysis, written by WyGISC 2016

A viewshed analysis of the study area was conducted in ArcGIS for Desktop 10.3.1, a commercial off-the-shelf GIS software product. The primary aim was to create a series of maps each one illustrating the area that is visible from a predefined location of interest (i.e. vantage point) within the study area. In addition to these viewshed maps, the following maps were also produced for the study area: (1) overview map depicting the spatial distribution of the vantage points; (2) landcover map based on the 2012 national landcover dataset (30m resolution NLCD); and (3) all vantage points viewsheds within a 60 mile radius of the study area perimeter.

The NLCD was further generalized into three landcover class of natural, developed and agriculture. Two statistics were then determined using Microsoft Excel 2013. First is the proportion of the viewshed area in each landcover class. This was calculated from aggregating the percentage of the viewshed area within each landcover class for each vantage point. The second statistic is the percentage of the viewshed area which overlapped different landcover classes within predefined distance zones of 0–0.05 miles, 0.5–3 miles and 3–60 miles of each vantage point. The general steps followed to create these statistics plus the map products described above are described below.

Creating and analyzing viewshed areas:

1. Collect project data. The following data were collected from various sources: 2012 NLCD (United States Geological Survey [USGS]), 10m resolution digital elevation data (National Elevation Dataset [NED]), national park (i.e. study area) boundary, vantage point locations (user-defined).
2. Change map projections. All datasets were re-projected to Lambert Conformal Conic Projection.
3. Create buffer region. In ArcGIS for Desktop, create a 60 mile buffer around the perimeter of the study area. The buffer tool is accessible via Analysis > Proximity > Buffer.
4. Add name attribute to vantage points layer. Create a field for storing the names of the vantage points (e.g. Point 1, Point 2, etc.) for labeling purposes.
5. Create a feature class of vantage points. Export study area vantage points into a feature class. Use the batch functionality for Conversion Tools > To Geodatabase > Feature Class to Feature Class tool with a definition query.
6. Generate viewshed for each vantage point. Use the Surface > Spatial Analyst Tools > Viewshed tool to create a viewshed for each vantage point based on the 10 m NED. Limit the analysis to the 60 mile buffer created in step 3.
7. Generalize NLCD into three landcover classes. Reclassify NCLD layer into three landcover classes of natural, developed and agriculture. Use the Spatial Analyst Tools > Reclassify tool.
8. Determine number of viewshed pixels overlaying each landcover class per vantage point. Use the Spatial Analyst Tools > Zonal tools > Zonal Statistics as Table tool to determine the number of viewshed area pixels for each landcover type per vantage point.

9. Determine percentage of viewsheds within three landcover classes. Use Microsoft Excel to determine the percentage of each viewshed (and combine viewsheds for study area) that were within each of the three landcover classes/zones
10. Finalize map products. Create cartographically-sound final maps.

Determining percentage of viewshed area that overlaps given landcover class at predefined distances from vantage points

The following steps were followed to achieve the above aim:

1. Create buffer zones of 0–0.5 miles, 0.5–3miles and 3–60 miles for each vantage point. The appropriate buffer tool is available in ArcGIS by navigating through: Analysis > Proximity> Multiple Ring Buffer tool
2. Create a landcover layer restricted to viewshed for each vantage point. This is achieved using ArcGIS' raster calculator found through: Spatial Analyst Tools > Map Algebra > Raster Calculator.
3. Separate layer created in step 2 into three layers, each one only displaying one of the landcover classes (e.g. agriculture). Use the Spatial Analyst Tools > Reclassify tool.
4. Determine number of viewshed pixels for each landcover class that falls within each buffered zone (e.g. number of agriculture pixels in 0–0.5 mile zone). Use the Spatial Analyst Tools > Zonal > Zonal Statistics as Table tool.
5. Determine percentage of each viewshed (and all viewsheds for a site combined) that fall within each landcover class (Natural, Developed, Agriculture) and within each distance zone (0–0.5 miles, 0.5–3 miles, 3–60 miles).

Notes

The viewsheds created here assume that there are no physical features which block the observer's line of sight.

The NLCD was resampled to 10m to match the resolution of the NED for analysis.

Where required, a viewshed can be generated from linear features such as road, trail or path sections.

Appendix C. List of Plant Species Found in 1998–2015 at AGFO

Table C1. List of all the plant species found in AGFO long-term plant community monitoring plots. The species are grouped by plant family. An "X" in the exotic column means that species is not native to the park or, in the case where only the genus was identified, there are some species within that genus that are exotic. Species considered to be rare in Nebraska are marked in the final column and the state conservation ranks are provided. Conservation rank definitions are in Table 4.8.2 of the report.

Family	Code	Scientific Name	Common Name	Exotic	Rare
Agavaceae	YUGL	*Yucca glauca*	soapweed yucca	–	–
Alismataceae	SACU	*Sagittaria cuneata*	arumleaf arrowhead	–	–
Amaranthaceae	AMAR	*Amaranthus arenicola*	sandhill amaranth	–	–
Anacardiaceae	RHTR	*Rhus trilobata*	skunkbush sumac	–	–
Apiaceae	CIMA2	*Cicuta maculata*	spotted water hemlock	–	S3S5
	CYGL99	*Cymopterus glomeratus*	plains springparsley	–	–
	LOOR	*Lomatium orientale*	Northern Idaho biscuitroot	–	–
	MUTE3	*Musineon tenuifolium*	slender wildparsley	–	–
Asclepiadaceae	ASIN	*Asclepias incarnata*	swamp milkweed	–	–
	ASSP	*Asclepias speciosa*	showy milkweed	–	–
	ASVI	*Asclepias viridiflora*	green comet milkweed	–	–
Asteraceae	AMAC2	*Ambrosia acanthicarpa*	flatspine burr ragweed	–	–
	AMBRO	*Ambrosia* spp.	ragweed	X	–
	AMPS	*Ambrosia psilostachya*	Cuman ragweed	–	–
	AMTR	*Ambrosia trifida*	great ragweed	–	–
	ARDR4	*Artemisia dracunculus*	tarragon	–	–
	ARFR4	*Artemisia frigida*	fringed sagewort	–	–
	BIFR	*Bidens frondosa*	devil's beggartick	–	–
	BREU	*Brickellia eupatorioides*	false boneset	–	–
	CIAR4	*Cirsium arvense*	Canada thistle	X	–
	CICA11	*Cirsium canescens*	prairie thistle	–	–
	CIFL	*Cirsium flodmanii*	Flodman's thistle	–	–
	CIRSI	*Cirsium* spp.	thistle	X	–
	COCA5	*Conyza canadensis*	horseweed	–	–
	CYXA	*Cyclachaena xanthifolia*	giant sumpweed	–	–
	DICA18	*Dieteria canescens*	hoary tansyaster	–	S2S4
	DYPA	*Dyssodia papposa*	fetid marigold	–	–
	ERBE2	*Erigeron bellidiastrum*	western daisy fleabane	–	–
	EROC	*Erigeron ochroleucus*	buff fleabane	–	S2
	ERPU2	*Erigeron pumilus*	shaggy fleabane	–	–

Table C1 (continued). List of all the plant species found in AGFO long-term plant community monitoring plots. The species are grouped by plant family. An "X" in the exotic column means that species is not native to the park or, in the case where only the genus was identified, there are some species within that genus that are exotic. Species considered to be rare in Nebraska are marked in the final column and the state conservation ranks are provided. Conservation rank definitions are in Table 4.8.2 of the report.

Family	Code	Scientific Name	Common Name	Exotic	Rare
Asteraceae (continued)	ERST3	*Erigeron strigosus*	prairie fleabane	–	–
	GUSA2	*Gutierrezia sarothrae*	broom snakeweed	–	–
	HEAN3	*Helianthus annuus*	common sunflower	–	–
	HELIA3	*Helianthus* spp.	sunflower	X	–
	HEPE	*Helianthus petiolaris*	prairie sunflower	–	–
	HEVI4	*Heterotheca villosa*	hairy false goldenaster	–	S1
	HYFI	*Hymenopappus filifolius*	fineleaf hymenopappus	–	–
	LASE	*Lactuca serriola*	prickly lettuce	X	–
	LAPU	*Lactuca pulchella*	blue lettuce	X	–
	LIPU	*Liatris punctata*	dotted blazing star	–	–
	LYJU	*Lygodesmia juncea*	rush skeletonplant	–	–
	MATA2	*Machaeranthera tanacetifolia*	tanseyleaf tansyaster	–	S3S5
	MUOB99	*Mulgedium oblongifolium*	blue lettuce	–	–
	PACA15	*Packera cana*	woolly groundsel	–	–
	RACO3	*Ratibida columnifera*	upright prairie coneflower	–	–
	SERI2	*Senecio riddellii*	Riddell's ragwort	–	–
	SOAR2	*Sonchus arvensis*	field sowthistle	X	–
	SOCA6	*Solidago canadensis*	Canada goldenrod	–	S3S5
	SOGI	*Solidago gigantea*	giant goldenrod	–	–
	SOMI2	*Solidago missouriensis*	Missouri goldenrod	–	–
	SOMO	*Solidago mollis*	velvety goldenrod	–	–
	SYER	*Symphyotrichum ericoides*	white heath aster	–	S3S5
	SYFA	*Symphyotrichum falcatum*	white prairie aster	–	S1
	SYLA6	*Symphyotrichum lanceolatum*	white panicle aster	–	–
	SYMPH4	*Symphyotrichum* spp.	aster	–	–
	TAOF	*Taraxacum officinale*	common dandelion	X	–
	TEAC	*Tetraneuris acaulis*	stemless four-nerve daisy	–	–
	TOEX2	*Townsendia exscapa*	stemless Townsend daisy	–	S3S5

Table C1 (continued). List of all the plant species found in AGFO long-term plant community monitoring plots. The species are grouped by plant family. An “X” in the exotic column means that species is not native to the park or, in the case where only the genus was identified, there are some species within that genus that are exotic. Species considered to be rare in Nebraska are marked in the final column and the state conservation ranks are provided. Conservation rank definitions are in Table 4.8.2 of the report.

Family	Code	Scientific Name	Common Name	Exotic	Rare
Asteraceae (continued)	TOGR	*Townsendia grandiflora*	largeflower Townsend daisy	–	S3S5
	TRDU	*Tragopogon dubius*	yellow salsify	X	–
	XAGR99	*Xanthisma grindelioides*	rayless tansyaster	–	–
	XASP99	*Xanthisma spinulosum*	lacy tansyaster	–	–
Boraginaceae	CRCA8	*Cryptantha cana*	mountain cryptantha	–	–
	CRCE	*Cryptantha celosioides*	buttecandle	–	–
	CRFE3	*Cryptantha fendleri*	sanddune cryptantha	–	S2S4
	CRMI5	*Cryptantha minima*	little cryptantha	–	–
	CRTH	*Cryptantha thyrsiflora*	calcareous cryptantha	–	S3S5
	LAOC3	*Lappula occidentalis*	flatspine stickseed	–	–
	LASQ	*Lappula squarrosa*	European stickseed	X	–
	LICA13	*Lithospermum caroliniense*	Carolina puccoon	–	–
	LIIN2	*Lithospermum incisum*	narrowleaf stoneseed	–	–
Brassicaceae	ALDE	*Alyssum desertorum*	desert madwort	X	–
	ARHO2	*Arabis holboellii*	Holboell's rockcress	–	–
	BOHO99	*Boechera holboellii*	Holboell's rockcress	–	–
	BRASS2	*Brassica* spp.	mustard	X	–
	BOCO4	*Boechera collinsii*	Collins' rockcress	–	–
	CAMI2	*Camelina microcarpa*	littlepod false flax	X	–
	DEPI	*Descurainia pinnata*	western tansymustard	–	S3S5
	DESO2	*Descurainia sophia*	herb sophia	X	–
	DRRE2	*Draba reptans*	Carolina draba	–	–
	ERCA14	*Erysimum capitatum*	sanddune wallflower	–	–
	LEDE	*Lepidium densiflorum*	common pepperweed	–	–
	PHLU99	*Physaria ludoviciana*	foothill bladderpod	–	–
	PHRE8	*Physaria reediana*	alpine bladderpod	–	S2S4
	SIAL2	*Sisymbrium altissimum*	tall tumblemustard	X	–
	THAR5	*Thlaspi arvense*	field pennycress	X	–
Cactaceae	ESVI2	*Escobaria vivipara*	spinystar	–	–
	MAHEM2	*Mammillaria heyderi* var. *meiacantha*	little nipple cactus	–	–
	OPFR	*Opuntia fragilis*	brittle pricklypear	–	–

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Cactaceae (continued)	OPMA2	*Opuntia macrorhiza*	twistspine pricklypear	–	–
	OPPO	*Opuntia polyacantha*	plains pricklypear	–	–
Capparaceae	PODO3	*Polanisia dodecandra*	redwhisker clammyweed	–	–
Caprifoliaceae	SYAL	*Symphoricarpos albus*	common snowberry	–	S1
	SYOC	*Symphoricarpos occidentalis*	western snowberry	–	–
Caryophyllaceae	ERHO13	*Eremogone hookeri*	Hooker's sandwort	–	S3S5
	PADE4	*Paronychia depressa*	spreading nailwort	–	–
	SIDR	*Silene drummondii*	Drummond's campion	X	–
	SILEN	*Silene* spp.	catchfly	–	–
Chenopodiaceae	CHAL7	*Chenopodium album*	lambsquarters	X	–
	CHBE4	*Chenopodium berlandieri*	pitseed goosefoot	–	–
	CHDE	*Chenopodium desiccatum*	aridland goosefoot	–	S2S4
	CHENO	*Chenopodium* spp.	goosefoot	X	–
	CHFR3	*Chenopodium fremontii*	Fremont's goosefoot	–	–
	CHPR5	*Chenopodium pratericola*	desert goosefoot	–	–
	CHSI2	*Chenopodium simplex*	mapleleaf goosefoot	–	–
	CORIS	*Corispermum* spp.	bugseed	X	–
	KOSC	*Kochia scoparia*	burningbush, kochia	X	–
	KRLA2	*Krascheninnikovia lanata*	winterfat	–	S3S5
	SALSO	*Salsola* spp.	Russian thistle	X	–
	SATR12	*Salsola tragus*	prickly Russian thistle	X	–
Cleomaceae	PESE99	*Peritoma serrulata*	Rocky Mountain beeplant	–	–
Commelinaceae	TRBR	*Tradescantia bracteata*	longbract spiderwort	–	–
	TROC	*Tradescantia occidentalis*	prairie spiderwort	–	–
Cucurbitaceae	ECLO	*Echinocystis lobata*	wild cucumber	–	–
Cyperaceae	CADU6	*Carex duriuscula*	needleleaf sedge	–	–
	CAFI	*Carex filifolia*	threadleaf sedge	–	–
	CAHA3	*Carex hallii*	deer sedge	–	S2S4
	CAHY4	*Carex hystericina*	bottlebrush sedge	–	–
	CAIN9	*Carex inops*	sun sedge	–	–
	CANE2	*Carex nebrascensis*	Nebraska sedge	–	–
	CAPE42	*Carex pellita*	woolly sedge	–	–
	CAPR5	*Carex praegracilis*	clustered field sedge	–	–

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Cyperaceae (continued)	CAREX	*Carex* spp.	sedge	–	–
	ELER	*Eleocharis erythropoda*	bald spikerush	–	–
	SCPU10	*Schoenoplectus pungens*	common threesquare	–	–
	SCTA2	*Schoenoplectus tabernaemontani*	softstem bulrush	–	–
Equisetaceae	EQLA	*Equisetum laevigatum*	smooth horsetail	–	–
Euphorbiaceae	CHGL13	*Chamaesyce glyptosperma*	ribseed sandmat	X	–
	EUGL3	*Euphorbia glyptosperma*	ribseed sandmat	X	–
	EURO5	*Euphorbia robusta*	horned spurge	X	–
	EUSE4	*Euphorbia serpens*	matted sandmat	–	–
	CRTE4	*Croton texensis*	Texas croton	–	–
	EUBR	*Euphorbia brachycera*	horned spurge	–	–
	EUMI5	*Euphorbia missurica*	prairie sandmat	–	S1S3
	EUPHO	*Euphorbia* spp.	spurge, sandmat	X	–
Fabaceae	ASAD11	*Astragalus adsurgens*	prairie milkvetch	–	–
	ASAG2	*Astragalus agrestis*	purple milkvetch	–	S1
	ASCE	*Astragalus ceramicus*	painted milkvetch	–	–
	ASCR2	*Astragalus crassicarpus*	groundplum milkvetch	–	–
	ASLA27	*Astragalus laxmannii*	Laxmann's milkvetch	–	–
	ASLO4	*Astragalus lotiflorus*	lotus milkvetch	–	–
	ASMI10	*Astragalus missouriensis*	Missouri milkvetch	–	–
	ASMO7	*Astragalus mollissimus*	woolly locoweed	–	–
	ASSE5	*Astragalus sericoleucus*	silky milkvetch	–	–
	ASSP6	*Astragalus spatulatus*	tufted milkvetch	–	–
	ASTRA	*Astragalus* spp.	milkvetch	–	–
	DACA7	*Dalea candida*	white prairie clover	–	–
	DAEN	*Dalea enneandra*	nineanther prairie clover	–	–
	DALEA	*Dalea* spp.	prairie clover	–	–
	DAPU5	*Dalea purpurea*	purple prairie clover	–	S3S5
	GLLE3	*Glycyrrhiza lepidota*	American licorice	–	–
	LAPO2	*Lathyrus polymorphus*	manystem pea	–	–
	LUAR3	*Lupinus argenteus*	silvery lupine	–	–
	LUPIN	*Lupinus* spp.	lupine	–	–

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Fabaceae (continued)	LUPL	*Lupinus plattensis*	Nebraska lupine	–	–
	LUPU	*Lupinus pusillus*	rusty lupine	–	–
	MELU	*Medicago lupulina*	black medick	X	–
	MEOF	*Melilotus officinalis*	yellow sweetclover	X	–
	MESA	*Medicago sativa*	alfalfa	X	–
	OXLA3	*Oxytropis lambertii*	purple locoweed	–	–
	OXSE	*Oxytropis sericea*	white locoweed	–	–
	PEAR6	*Pediomelum argophyllum*	silverleaf Indian breadroot	–	–
	PEES	*Pediomelum esculentum*	large Indian breadroot	–	–
	PSLA3	*Psoralidium lanceolatum*	lemon scurfpea	–	–
	PSTE5	*Psoralidium tenuiflorum*	slimflower scurfpea	–	–
	THRH	*Thermopsis rhombifolia*	golden pea	–	–
Grossulariaceae	RIAM2	*Ribes americanum*	American black currant	–	–
Hydrophyllaceae	ELNY	*Ellisia nyctelea*	Aunt Lucy	–	–
	PHHA	*Phacelia hastata*	silverleaf phacelia	–	S2S4
Iridaceae	IRPS	*Iris pseudacorus*	pale yellow iris	X	–
Juncaceae	JUBA	*Juncus balticus*	Baltic rush	–	–
	JUNCU	*Juncus* spp.	rush	X	–
Lamiaceae	HEDR	*Hedeoma drummondii*	Drummond's false pennyroyal	–	–
	HEHI	*Hedeoma hispida*	rough false pennyroyal	–	–
	LYAM	*Lycopus americanus*	American water horehound	–	–
	LYAS	*Lycopus asper*	rough bugleweed	–	–
	MEAR4	*Mentha arvensis*	wild mint	–	–
	SCLA2	*Scutellaria lateriflora*	blue skullcap	–	–
Lemnaceae	LEMI3	*Lemna minor*	common duckweed	–	S3S5
Lentibulariaceae	UTRIC	*Utricularia* spp.	bladderwort	–	–
Liliaceae	ALTE	*Allium textile*	textile onion	–	–
	CANU3	*Calochortus nuttallii*	sego lily	–	–
	FRAT	*Fritillaria atropurpurea*	spotted fritillary	–	S2
	MAST4	*Maianthemum stellatum*	starry false lily of the valley	–	–
Linaceae	LIRI	*Linum rigidum*	stiffstem flax	–	–
Loasaceae	MEDE2	*Mentzelia decapetala*	tenpetal blazingstar	–	–
Malvaceae	SPCO	*Sphaeralcea coccinea*	scarlet globemallow	–	–

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Melanthiaceae	TOVE2	*Toxicoscordion venenosum*	meadow deathcamas	–	–
Nyctaginaceae	ABFR2	*Abronia fragrans*	snowball sand verbena	–	–
	MIHI	*Mirabilis hirsuta*	hairy four o'clock	–	–
	MILI3	*Mirabilis linearis*	narrowleaf four o'clock	–	–
Onagraceae	EPLE2	*Epilobium leptophyllum*	bog willowherb	–	–
	GAPA6	*Gaura parviflora*	velvetweed	X	–
	OEAL	*Oenothera albicaulis*	whitest evening primrose	–	–
	OENU	*Oenothera nuttallii*	Nuttall's evening-primrose	–	–
	OESE3	*Oenothera serrulata*	yellow sundrops	–	–
	OESU99	*Oenothera suffrutescens*	scarlet beeblossom	–	–
Orobanchaceae	ORFA	*Orobanche fasciculata*	clustered broomrape	–	–
Papaveraceae	ARPO2	*Argemone polyanthemos*	crested pricklypoppy	–	–
Pinaceae	PIPU	*Picea pungens*	blue spruce	–	–
Plantaginaceae	PLER	*Plantago eriopoda*	redwool plantain	–	S3S5
	PLPA2	*Plantago patagonica*	woolly plantain	–	S2S4
Poaceae	ACHY	*Achnatherum hymenoides*	Indian ricegrass	–	–
	ANGE	*Andropogon gerardii*	big bluestem	–	–
	ANHA	*Andropogon hallii*	sand bluestem	–	–
	ARPU9	*Aristida purpurea*	purple threeawn	–	S3S5
	BOCU	*Bouteloua curtipendula*	sideoats grama	–	–
	BOGR2	*Bouteloua gracilis*	blue grama	–	–
	BRIN2	*Bromus inermis*	smooth brome	X	–
	BRJA	*Bromus japonicus*	Japanese brome	X	–
	BROMU	*Bromus* spp.	brome	X	–
	BRTE	*Bromus tectorum*	cheatgrass	X	–
	CALO	*Calamovilfa longifolia*	prairie sandreed	–	–
	CAST36	*Calamagrostis stricta*	slimstem reedgrass	–	–
	DISP	*Distichlis spicata*	saltgrass	–	–
	ELEL5	*Elymus elymoides*	squirreltail	–	–
	ELLA3	*Elymus lanceolatus*	thickspike wheatgrass	–	S1
	ELRE4	*Elymus repens*	quackgrass	X	–
	ELTR7	*Elymus trachycaulus*	slender wheatgrass	–	S1
	ELYMU	*Elymus* spp.	wildrye	X	–

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Poaceae (continued)	FEOC	*Festuca occidentalis*	western fescue	–	–
	GLST	*Glyceria striata*	fowl mannagrass	–	–
	HECO26	*Hesperostipa comata*	needle and thread	–	–
	HOJU	*Hordeum jubatum*	foxtail barley	–	–
	KOMA	*Koeleria macrantha*	prairie Junegrass	–	–
	LEOR	*Leersia oryzoides*	rice cutgrass	–	–
	MUAS	*Muhlenbergia asperifolia*	scratchgrass, alkali muhly	–	–
	MUCU3	*Muhlenbergia cuspidata*	plains muhly	–	–
	MUHLE	*Muhlenbergia* spp.	muhly	–	–
	MUME2	*Muhlenbergia mexicana*	Mexican muhly	–	–
	MUPA99	*Muhlenbergia paniculata*	tumblegrass	–	–
	MUPU2	*Muhlenbergia pungens*	sandhill muhly	–	–
	MURA	*Muhlenbergia racemosa*	marsh muhly	–	–
	NAVI4	*Nassella viridula*	green needlegrass	–	–
	PACA6	*Panicum capillare*	witchgrass	–	S3S5
	PANIC	*Panicum* spp.	panicgrass	X	–
	PASM	*Pascopyrum smithii*	western wheatgrass	–	–
	PAVI2	*Panicum virgatum*	switchgrass	–	–
	POCO	*Poa compressa*	Canada bluegrass	X	–
	POPA2	*Poa palustris*	fowl bluegrass	–	–
	POPR	*Poa pratensis*	Kentucky bluegrass	X	–
	POSE	*Poa secunda*	Sandberg bluegrass	–	–
	SCSC	*Schizachyrium scoparium*	little bluestem	–	–
	SONU2	*Sorghastrum nutans*	Indiangrass	–	–
	SPCR	*Sporobolus cryptandrus*	sand dropseed	–	–
	SPGR	*Spartina gracilis*	alkali cordgrass	–	–
	SPOB	*Sphenopholis obtusata*	prairie wedgescale	–	S2S4
	SPPE	*Spartina pectinata*	prairie cordgrass	–	–
	THIN6	*Thinopyrum intermedium*	intermediate wheatgrass	X	–
	VUOC	*Vulpia octoflora*	sixweeks fescue	–	–
Polemoniaceae	PHAN4	*Phlox andicola*	prairie phlox	–	–
	PHHO	*Phlox hoodii*	spiny phlox	–	–
Polygonaceae	ERAN4	*Eriogonum annuum*	annual buckwheat	–	–
	ERCE2	*Eriogonum cernuum*	nodding buckwheat	–	S1

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Polygonaceae (continued)	ERFL4	*Eriogonum flavum*	alpine golden buckwheat	–	–
	ERPA9	*Eriogonum pauciflorum*	fewflower buckwheat	–	S3S5
	FACO	*Fallopia convolvulus*	black bindweed	X	–
	PEAM8	*Persicaria amphibia*	longroot smartweed	–	S3S5
	PELA22	*Persicaria lapathifolia*	curlytop knotweed	–	–
	POAV	*Polygonum aviculare*	prostrate knotweed	X	–
	PORA3	*Polygonum ramosissimum*	bushy knotweed	–	–
	RUVE2	*Rumex venosus*	veiny dock	–	–
Potamogetonaceae	POTAM	*Potamogeton*	pondweed	–	–
Rosaceae	ROWO	*Rosa woodsii*	Woods' rose	–	–
Rubiaceae	GATI	*Galium tinctorium*	stiff marsh bedstraw	–	–
Salicaceae	SAER	*Salix eriocephala*	Missouri River willow	–	S3S5
	SAIN3	*Salix interior*	sandbar willow	–	–
	SALIX	*Salix* spp.	willow	–	–
Santalaceae	COUM	*Comandra umbellata*	bastard toadflax	–	–
Scrophulariaceae	CASE5	*Castilleja sessiliflora*	Great Plains Indian paintbrush	–	–
	PEAL2	*Penstemon albidus*	white penstemon	–	–
	PEAN4	*Penstemon angustifolius*	broadbeard beardtongue	–	–
	PEER	*Penstemon eriantherus*	fuzzytongue penstemon	–	S3S5
	VEAN2	*Veronica anagallis-aquatica*	water speedwell	–	–
	VETH	*Verbascum thapsus*	common mullein	X	–
Solanaceae	PHHI8	*Physalis hispida*	prairie groundcherry	–	–
	PHVI5	*Physalis virginiana*	Virginia groundcherry	–	–
	PHYSA	*Physalis* spp.	groundcherry	–	–
	SOTR	*Solanum triflorum*	cutleaf nightshade	–	S3S5
Sparganiaceae	SPEU	*Sparganium eurycarpum*	broadfruit bur-reed	–	–
Typhaceae	TYAN	*Typha angustifolia*	narrowleaf cattail	–	–
	TYLA	*Typha latifolia*	broadleaf cattail	–	–
Urticaceae	PAPE5	*Parietaria pensylvanica*	Pennsylvania pellitory	–	–
	URDI	*Urtica dioica*	stinging nettle	–	–
Verbenaceae	VEHA2	*Verbena hastata*	swamp verbena	–	–
Violaceae	VINU2	*Viola nuttallii*	Nuttall's violet, yellow prairie violet	–	–

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

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