National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Natural Resource Condition Assessment

Fort Laramie National Historic Site

Natural Resource Report NPS/FOLA/NRR—2018/1680

ON THE COVER
Photo by John Gilpin

Natural Resource Condition Assessment

Fort Laramie National Historic Site

Natural Resource Report NPS/FOLA/NRR—2018/1680

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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 Fort Laramie National Historic Site. 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.

Fort Laramie National Monument was established in 1938 and designated as a National Historic Site (NHS) in 1960. The purposes of the park include preserving and interpreting the extensive historic and cultural resources for which the park is well known, as well as protecting the resources at the confluence of the Laramie and North Platte Rivers.

The assessment for Fort Laramie NHS 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 Fort Laramie NHS. 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, conditions varied from good (viewshed), to warranting moderate concern (night sky), to warranting significant concern (soundscape). Increased development of industrial infrastructure around the park has contributed to the poor conditions of soundscape and the deteriorating night sky quality.

Supporting Environment—or physical environment—resources included air quality, surface water quality, and geology. Air quality was of moderate concern, and water quality and geology were in good condition.

The natural resources that composed the Biological Integrity category included vegetation, birds, bats, and pollinators. These resources were all of moderate concern, except for birds, for which we were unable to assign a condition in the absence of specific management goals.

This assessment includes a general background on the NRCA process (Chapter 1), an introduction to Fort Laramie NHS and the natural resources included in the assessment (Chapter 2), a description of methods (Chapter 3), condition assessments for 10 natural resources (Chapter 4), and a summary of findings accompanied by management considerations (Chapter 5).

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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

[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.

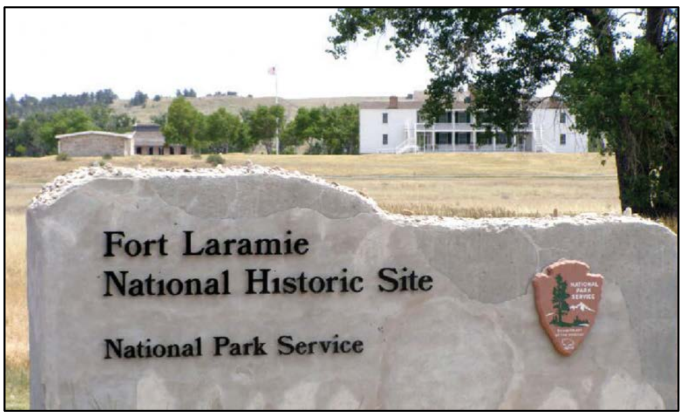
Chapter 2. Introduction and Resource Setting

2.1. Introduction

2.1.1. Enabling Legislation

Fort Laramie National Monument was established on July 16, 1938, by Presidential Proclamation No. 2292 (53 Stat. 2461), and redesignated Fort Laramie National Historic Site (NHS) in 1960 (Mattes 1980). The purpose of the Site is to:

- Preserve the historic scene at the confluence of the Laramie and North Platte Rivers
- Preserve the resources at the confluence of the Laramie and North Platte Rivers
- Interpret the roles and significance of the diverse and vibrant cultures that interacted at the crossroads of the nation moving west



Entrance to Fort Laramie National Historic Site (Photo: Chris Light 2008, Wikipedia).

2.1.2. Geographic Setting

Fort Laramie NHS is located in the grasslands of southeastern Wyoming, 25 miles west of the Wyoming-Nebraska state line and 80 miles north of Wyoming-Colorado border. Situated near the confluence of the Laramie and North Platte Rivers in the upper Platte River Valley, Fort Laramie consists of approximately 833 acres of land that preserve, illustrate, and interpret events that contributed to westward expansion and the settlement of the American West (NPS 2017).

2.1.3. Visitation Statistics

Annual visitation data for Fort Laramie NHS are available for 1939-2015. The total number of annual visitors ranged from 1,330 in 1943 to 157,655 in 1972, with an average of 61,132 visitors, annually. The number of recreation visitors in 2015 was 51,616. Visitation data by month are available for 1979-2015. 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 2016a).

2.2. Natural Resources

A summary of the natural resources at Fort Laramie National Historic Site 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, Vegetation, Birds, Bats, and Pollinators.

2.2.1. Ecological Units and Watersheds

Fort Laramie NHS is located in the Northwestern Mixed and Western Short Grasslands ecoregions of the Northern Great Plains in southeastern Wyoming (Ricketts et al. 1999).

2.2.2. Resource Descriptions

In this section we have summarized background information about key natural resources at Fort Laramie NHS. 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.

<u>Viewshed</u>

The historic fort structures, cultural landscapes, the Laramie and North Platte Rivers, and views of the mountains contribute to visitor experience at Fort Laramie NHS. The landscapes in and around the park offer visitors' opportunities to enjoy visual settings that guided trappers and traders in the overland fur trade and emigrants on the westward migration trails. Tribes and early settlers would have likely seen western short grassland prairie, once the dominant land cover in the region, stretching for miles in all directions.

President Franklin D. Roosevelt established Fort Laramie as a National Monument in 1938 to preserve the lands and structures as a public historic site. In April 1960, the boundaries of Fort Laramie were expanded and the monument was redesignated as a National Historic Site. Park mangers preserve the land and structures of Fort Laramie NHS for their historic, interpretive, and cultural values. Preserving the historic aesthetic is a primary goal related to the management of park viewsheds.

<u>Night Sky</u>

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.

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.

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.

Fort Laramie NHS is surrounded by agricultural operations and roads, and located less than two kilometers (1.2 miles) west of the small town of Fort Laramie. Primary sources of non-natural sounds within the park include automobile and railway traffic, visitor conversations and associated acoustics, maintenance operations, agricultural activities, and air traffic passing overhead.

Air Quality

Fort Laramie NHS is designated a Class II air quality area. This protective classification means that the NPS unit receives federal assistance to protect and improve its air quality. Similar to other small park units, many of the threats to clean air at Fort Laramie NHS come from pollution sources outside of park boundaries. As a result, protection and improvement of air quality within the park requires collaboration with other stakeholders. The Clean Air Act makes a provision for federal land managers to participate in regulatory decision making when protected federal lands, such as NPS units, might be affected. Participation may include consultations, written comments, recommendations, and review.

The American Lung Association (ALA) compiles a State of the Air report for each state, and assigns scores for air quality by county. Fort Laramie NHS is located in Goshen County, Wyoming, where there were not enough monitoring data from 2014 to 2015 to assign a score, but adjacent Laramie County received the highest possible grade (A) for that time period.

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 affect public health.

Fort Laramie NHS is part of the Northern Great Plains Network (NGPN) and is located in southeast Wyoming at the confluence of the Laramie and North Platte Rivers, which eventually flow east to the Missouri River. The Laramie River is a prominent natural feature that bisects the park unit and is an important resource for plants and wildlife in the region. The North Platte River that bounds Fort Laramie NHS on the east side is larger than the Laramie River, but the section of Laramie River that winds through the park unit is a higher regional priority for NPS.

Geology

Geological resources underlie and affect many other resources within National Park System units. In Northern Great Plains area where Fort Laramie NHS is located, most of the bedrock is composed of soft Upper Cretaceous and Tertiary sediment strata. 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 and immediately surrounding Fort Laramie NHS, the oldest rocks exposed within the boundaries of Fort Laramie NHS are Quaternary river deposits of Pleistocene age (2.58 million to 11,700 years ago) and younger.

The Tertiary strata that crop out in the region around Fort Laramie are an important sequence of rocks that 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 reduced forest cover and correspondingly increased open grasslands, as reflected in fossil soils. These deposits stretch for hundreds of miles across the region.

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.

Fort Laramie NHS, established in 1938 to protect and preserve the well-known military post, covers 833 acres on the boundary of the northern mixed-grass and short-grass prairie region. The park is a mosaic of disturbed old-fields, riparian forests, and native prairie and is host to 376 plant species.

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.

Fort Laramie NHS is located within the badlands and prairies bird conservation region. The badlands and prairies 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 can be found at Fort Laramie NHS.

Invertebrate Pollinators

Wyoming invertebrate pollinators include native insects and honey bees that vary in diversity and abundance across the landscape. The most recent invertebrate survey available for Fort Laramie NHS confirmed that the park is home to a total of 16 species, though the authors suggest that the true number of species present is likely to be much higher. Pearl crescent (*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 Fort Laramie NHS, local census data are lacking for the park.

In Wyoming, wind farms present a growing challenge for invertebrate pollinators as insect kills on turbine blades can be substantial. Some plants of concern in the region around Fort Laramie NHS, such as alpine feverfew (*Parthenium alpinum*), likely rely on pollinators other than butterflies or bees.

Bats

Bats have many important ecological roles and are one of the most diverse groups of mammals, accounting for about 20% of all mammal species globally (1,200). These winged mammals consume thousands of pounds of insects annually, including some damaging agricultural pests, thereby saving billions of dollars in agricultural costs. In some regions, bats are critical for the propagation of many plants. Even bat guano (droppings) provides unique habitat to some specialist organisms. Some bats are considered by researchers to be keystone species, a species that has a much greater effect on its ecosystem than would be expected given its biomass, and can be bioindicators of the health of a broad range of organisms.

National Park Service lands are important reference and monitoring sites for bat populations. The NPS is dedicated to protecting bats and their habitat; at the time of this assessment, over 40 parks were host to at least 43 projects to protect bats and gain insight into white nose syndrome. Among NPS units that have caves, mines, and old buildings for roosting, about 40 of the 47 resident of US bat species occur on NPS land.

2.2.3. Resource Issues Overview

Preserving the natural resources found in Fort Laramie NHS is one of the founding goals for the park. The setting at the confluence of the Laramie and North Platte Rivers provides rich opportunities for outreach and research, and maintaining the health of the natural resources helps to attract visitors with a broad range of interests.

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. Additionally, the park has the added challenge of balancing natural resource management with its other major goals of preserving the historical setting and cultural resources within its boundaries.

2.3. Resource Stewardship

2.3.1. Management Directive and Planning Guidance

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

> *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.

2.4. Literature Cited

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Ricketts, T. H., editor. 1999. Terrestrial ecoregions of North America: a conservation assessment. Island Press, Washington, D.C.

Chapter 3. Study Scoping and Design

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 Fort Laramie NHS 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.

Fort Laramie National Historic Site (Photo: Paul Hermans 2014, Wikipedia).

3.2. Project Design and Methods

3.2.1. Project Phases

We used a two-phase process for completing the assessment for Fort Laramie NHS. 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 Fort Laramie NHS 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 Fort Laramie NHS, Agate Fossil Beds NM, 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 Fort Laramie NHS.

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 frame-work to guide the NRCA
  - Identify critical, park-specific bio-physical resources for assessment
  - Identify the key indicators of re-source 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 3.2.1) 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 3.2.1. Natural Resource Condition Assessment Framework for Fort Laramie NHS.

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)
	Night Sky	Night sky quality	Sky Quality Index (SQI)
	Night Sky	Natural light environment	Anthropogenic Light Ratio (ALR)

Table 3.2.1 (continued). Natural Resource Condition Assessment Framework for Fort Laramie NHS.

Context	Resource	Indicator	Measure
I. Landscape condition context (continued)	Soundscape	Anthropogenic impact	Mean L_{50} 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	Methylmercury Rating
	Water quality	Acidity	pH
	Water quality	Dissolved oxygen	mg/L
	Water quality	Specific conductivity	S/m
	Water quality	Temperature	°C
	Water quality	Turbidity	NTUs
	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	Sediment transport	Natural range of variation: flooding consistency
	Geology	Sediment transport	Natural range of variation: channel position
III. Biological integrity	Vegetation	Upland plant community structure and composition	Native species richness
	Vegetation	Upland plant community structure and composition	Evenness
	Vegetation	Exotic plant early detection and management	Relative cover of exotic species
	Vegetation	Exotic plant early detection and management	Annual brome cover
	Vegetation	Riparian forest	Plains cottonwood stand seral stage

Table 3.2.1 (continued). Natural Resource Condition Assessment Framework for Fort Laramie NHS.

Context	Resource	Indicator	Measure
III. Biological integrity (continued)	Vegetation	Riparian forest	Percent of 20 riparian plots with native deciduous seedlings
	Breeding birds	Species diversity	Species richness
	Breeding birds	Species abundance	Mean density
	Breeding birds	Conservation value	Mean priority ranking
	Bats	Bat species status (eleven species assessed individually)	Population growth rate
	Bats	Bat species status (eleven species assessed individually)	Level of conservation concern
	Bats	Exposure to white-nose syndrome	Presence, absence, or proximity
	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 Fort Laramie NHS and incorporated their edits and comments. In Chapter 5 we summarize management goals and data gaps, based 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 3.2.1), 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.

<u>Data</u>

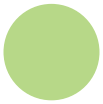
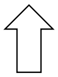
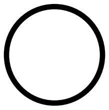
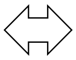
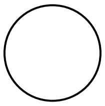
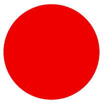
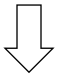
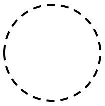
In this assessment we searched for data that were collected within the boundaries of Fort Laramie NHS or as near to the park as possible. If these data were unavailable, we considered data in the broader region as acceptable to natural resource managers and leadership at Fort Laramie NHS. We used the 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.

<u>Analyses</u>

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 3.2.2). 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 3.2.2. Symbolism for condition, confidence, and trend.

Condition Status		Trend in Condition		Confidence in Assessment	
	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 Resources 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 3.2.3).

Table 3.2.3. Points determining overall indicator condition.

Resource condition		Points for overall condition
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 3.2.2.) 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 reliable 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 3.2.2). 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 values associated with this park became a founding principle of the 1916 Organic Act (54 U.S.C. §100101) that established the National Park Service (NPS) and other park units, such as Fort Laramie National Historic Site (Figure 4.1.1).

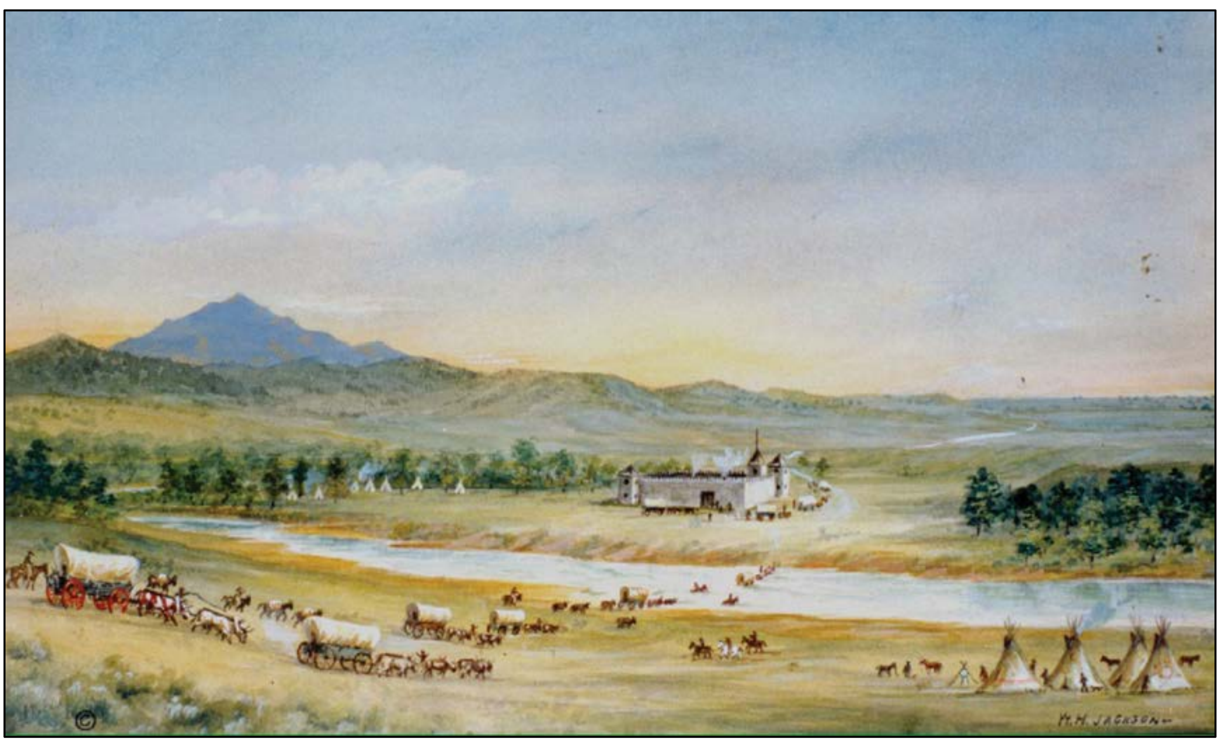


Figure 4.1.1. 1933 William Henry Jackson watercolor. Fort Laramie, seated at the confluence of the Laramie and North Platte Rivers, was an important stopping point on the westward migration trails and a nexus for the overland fur trade in the 1800s. Laramie Peak rises out of the foothills west of the fort, as depicted. These natural features contribute to visitor experience today. Image courtesy of Scotts Bluff NM collection.

The National Park Service prioritizes conserving scenery for the enjoyment of visitors and current and future generations (54 U.S.C. §100101). 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 resources within a park unit encompass the visible areas 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.

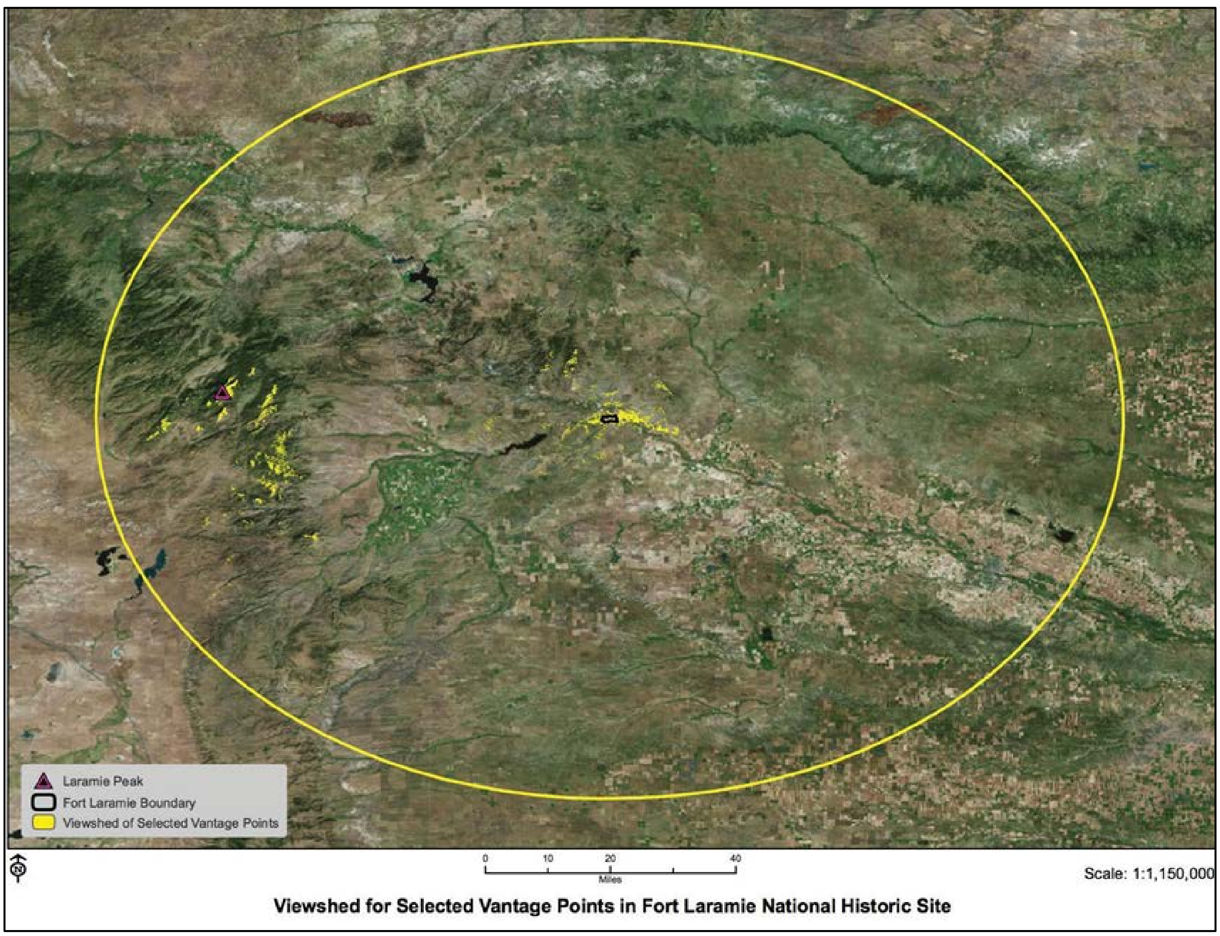


Figure 4.1.2. Viewshed of all areas visible from one or more vantage points at Fort Laramie NHS used in the digital viewshed assessment. Laramie Peak, the most prominent peak of the Laramie Mountain Range, is visible to the west of Fort Laramie NHS. Map created by WyGISC (2016) from Landsat imagery.

Regional Context

At Fort Laramie NHS, the historic fort structures, cultural landscapes, the Laramie and North Platte Rivers, and views of the mountains contribute to visitor experience. The landscapes in and around the park offer visitors' opportunities to enjoy visual settings that guided emigrants on the westward migration trails and in the overland fur trade. Tribes and early settlers would have likely seen western short grassland prairie, once the dominant land cover in the region (Ricketts et al. 1999), stretching for miles in all directions. The towering cottonwood trees that now provide wildlife habitat, shade, and ambience at Fort Laramie NHS were not yet seeded in the late 1800s; these trees provide visual historic context for visitors looking through old photographs of the park.

Despite the preserved buildings and historic milieu of Fort Laramie NHS, the landscapes of the region around the National Historic Site are now very different than they were in the1800s. 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 Fort Laramie NHS.

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.

President Franklin D. Roosevelt established Fort Laramie as a National Monument in 1938 to preserve the lands and structures as a public historic site. In April 1960, the boundaries of Fort Laramie were expanded and the monument was redesignated as a National Historic Site. Park mangers preserve the land and structures of Fort Laramie NHS for their historic, interpretive, and cultural values. Preserving the historic aesthetic is a primary goal related to the management of park viewsheds.

4.1.3. Methods

We assessed viewshed condition within Fort Laramie NHS 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 direction 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 material for Fort Laramie NHS (NPS 2016), historic preservation interpretive materials (Cyark et al. 2016), 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. To complete the adapted VRI analyses in a timely manner, we further limited the vantage point selection for that process to three points representative of the views in Fort Laramie NHS (vantage points 2 [Park Entrance], 5 [Pony Express Marker], and 6 [Parade Grounds]). We adapted the VRI process developed by NPS-ARD (Sullivan and Meyer 2015) to use in this NRCA. This adaptation was necessary because full viewshed assessments have not yet been completed for Fort Laramie NHS. 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.

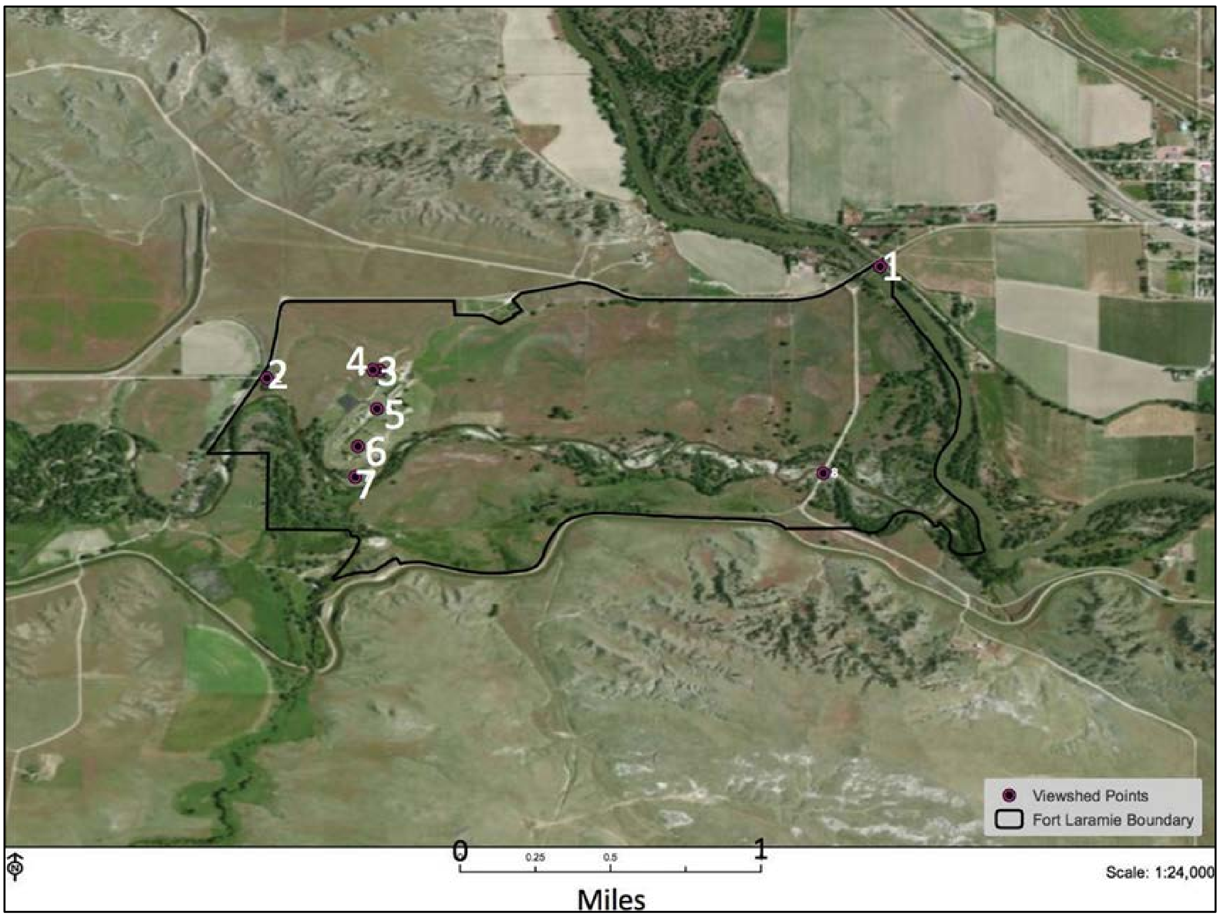


Figure 4.1.3. Vantage points used in the digital viewshed analysis for Fort Laramie NHS. For the Visual Resource Inventory, only vantage points 2 (Park Entrance), 5 (Pony Express Marker), and 6 (Parade Grounds) were used. Map created by WyGISC (2016) from Landsat imagery.

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 only.

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 2015b).

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 landscape character integrity.

Resource condition		Character integrity value
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.

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 2015b).

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*.

Table 4.1.2. View shed condition categories for vividness of the view.

Resource condition		Vividness rating
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 scores 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 2015b).

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 visual harmony.

Resource condition		Visual harmony rating
Warrants significant concern		1 – 5
Warrants moderate concern		6 – 10
Resource in good condition		> 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 National Monument, Agate Fossil Beds National Monument, 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).

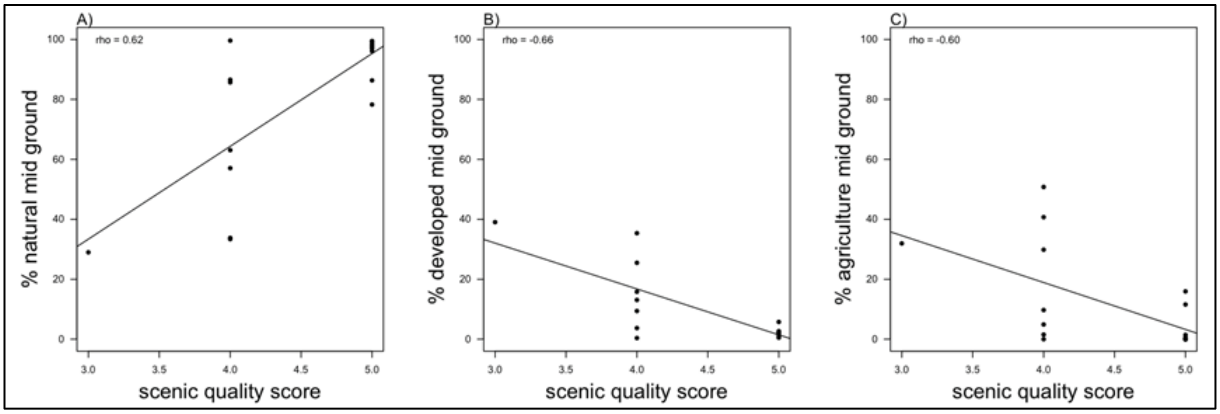


Figure 4.1.7. Relationships between scenic quality score and land cover. Rho is the correlation between scenic quality score and the percentage of each ground cover type.

Measure of Land Cover Content: Percentage of Natural Cover in the 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 *Resource 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
Warrants significant concern	red circle	≤ 50
Warrants moderate concern	yellow circle	50 < and ≤ 75
Resource in good condition	green circle	76 – 100

Measure of Land Cover Content: Percentage of Developed Cover in the Mid-ground

Developed land cover was negatively correlated with scenic quality score in the middle ground distance (0.5-03.0 miles) 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 highest 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 *Resource 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
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 the Mid-ground

Agricultural land cover was negatively correlated with scenic quality score in the middle ground distance (0.5-3.0 miles) 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
Warrants significant concern		> 25
Warrants moderate concern		> 13 and < 25
Resource in good condition		< 13

Data Sources

To evaluate viewpoints for scenic quality, we used scenic photos available online from Fort Laramie NHS (NPS 2016), virtual tours and interpretive panoramas (Cyark et al. 2016), photographs taken by visitors and linked to vantage locations in Google Earth (Google Earth 2014a), and, when available, digitally "stitched" panoramic photos from Google Earth street and ground views at three locations (Google Earth 2014b, 2014c, 2014d). 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 were completed by the Wyoming Geographic Information Science Center (WyGISC) for each vantage point (see Appendix A for maps, Appendix B for methods). 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

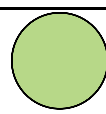
Potential trend categories were *Improving*, *Unchanging*, or *Deteriorating*. To calculate a trend estimate for indicators, we sought viewshed data that were collected at least twice over a five-year period and met the conditions for a High confidence rating. If there were no data available that met 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: Medium
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 Fort Laramie NHS 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			
		Park entrance (vantage point 2)	Pony express monument (vantage point 5)	Parade grounds (vantage point 6)	Park average
Landscape character integrity	Landscape character elements	4	4.5	5	4.5
	Quality and condition of elements	4	4.5	5	4.5
	Inconsistent elements	2	4	4	3.3
	Total	**10**	**13**	**14**	**12.3**
Vividness	Focal points	3.5	3.5	4	3.7
	Forms/lines	4	4.5	5	4.5
	Colors	3.5	4	4	3.8
	Total	**11**	**12**	**13**	**12**
Visual harmony	Spatial relationship	3	4	5	4
	Scale	4.5	4	5	4.5
	Color	4	4	5	4.3
	Total	**11.5**	**12**	**15**	**12.8**

Confidence

Scenic quality data were not available from full VRI assessments conducted within the park. We conducted remote assessments using geotagged photographs and digitally stitched panoramas (Cyark et al. 2016). The confidence rating was *Medium*.

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

Condition

Land cover content percentages for natural cover, developed cover and agricultural cover at mid-ground distances were 73.97%, 7.52%, and 18.52% respectively (Figure 4.1.8). Measurements for natural and developed cover related to the *Resource in Good Condition* category, while measurements for agricultural cover related to the *Warrants Moderate Concern* category. Overall, land cover content condition was placed in the *Resource in Good Condition* category.

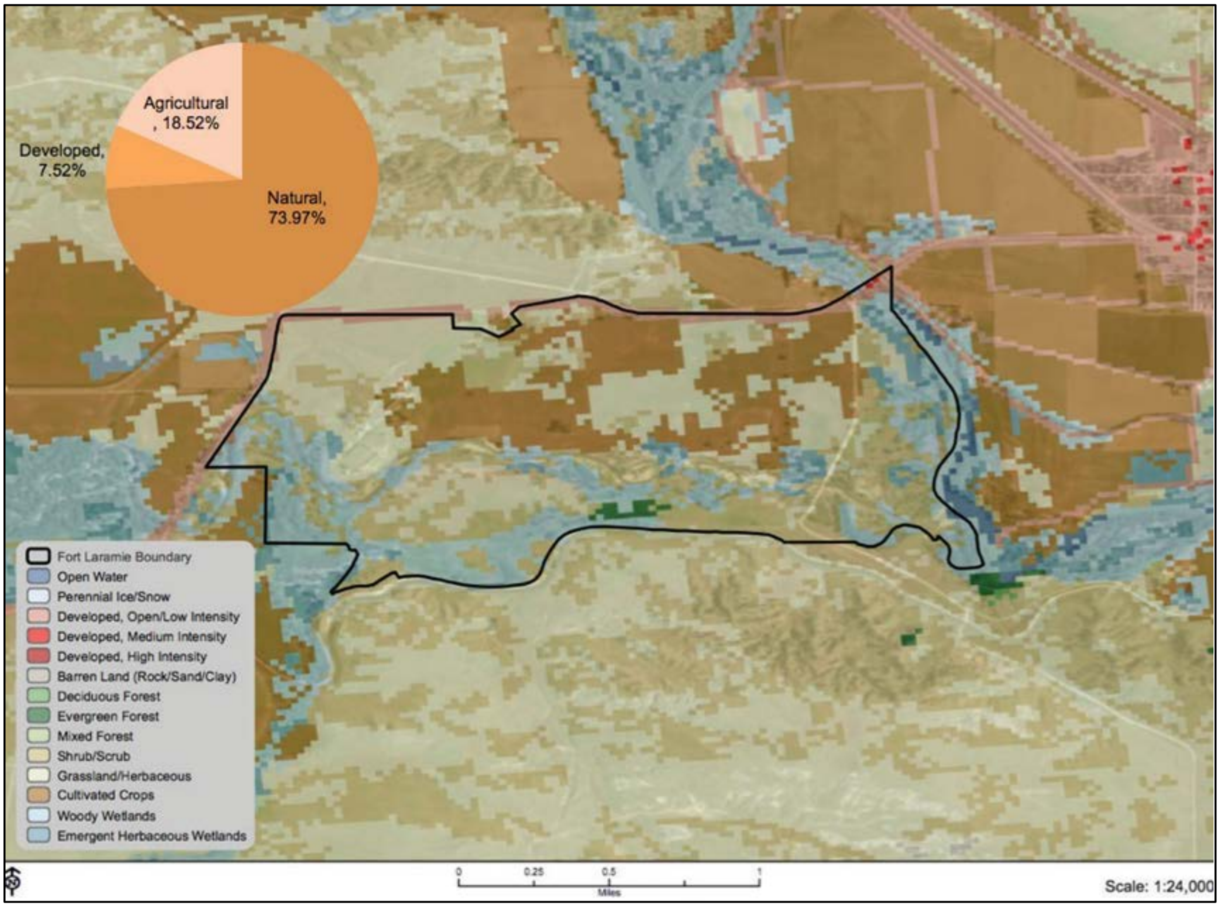


Figure 4.1.8. Mid-ground land cover content. Natural cover includes barren land, deciduous forest, evergreen forest, mixed forest, shrub/scrub, grassland/herbaceous, woody wetlands, and emergent herbaceous wetlands. Agricultural cover includes cultivated crops. Developed land includes developed with 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

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		

The overall viewshed condition 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 Fort Laramie NHS 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 Fort Laramie NHS in the *Resource in Good Condition* category.

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	Medium	Not available	The average landscape character integrity score from three different viewpoints in Fort Laramie NHS was 12.3; this placed landscape character integrity in the *Resource in Good Condition* category. Geotagged photographs digitally stitched panoramas were available for assessments so confidence was *Medium*. Trend was *Not Available*.
	Vividness	Resource in good condition	Medium	Not available	The average vividness score from three different viewpoints in Fort Laramie NHS was 12; this placed landscape character integrity in the *Resource in Good Condition* category. Geotagged photographs digitally stitched panoramas were available for assessments so confidence was *Medium*. 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	Medium	Not available	The visual harmony score from three different viewpoints in Fort Laramie NHS was 12.8; this placed landscape character integrity in the *Resource in Good Condition* category. Geotagged photographs digitally stitched panoramas were available for assessments so confidence was *Medium*. 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 three different Fort Laramie NHS viewpoints comprised 73.97% 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 three different Fort Laramie NHS viewpoints comprised 7.52% 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	Warrants moderate concern	High	Not available	Average 2011 mid-ground agricultural land cover visible from the three different Fort Laramie NHS viewpoints comprised 18.52% of the viewed landscape; this placed mid-ground agricultural land cover in the *Warrants Moderate Concern* category. The GIS analysis of land cover used the most recent NLCD data so confidence was *High*. Trend was *Not Available*

Confidence

Confidence was *Medium* for Scenic Quality and *High* for Land Cover Content, so the score for overall confidence was 75, which met the requirements for *High* 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 Goshen County Economic Development Corp (Goshen County Economic Development Corp 2010) and Goshen County's land use plan (Goshen County Wyoming 1996). Fort Laramie is surrounded primarily by natural or agricultural lands with the town of Fort Laramie, WY nearby. For this reason, county planning documents and economic development plans provided the most useful information regarding potential stressors to the viewshed.

Based on the unpublished developmental guidance of the NPS-ARD (Meyer 2016), we evaluated the level of viewshed vulnerability at Fort Laramie NHS using likelihood of visual change, magnitude of visual change, and mitigation constraints as the basis for our assessment of stressors to this resource. The protections in place and the projected development plans in the area surrounding Fort Laramie NHS indicate that all vulnerability factor ratings are low. In the five years preceding this assessment, a pipeline-to-rail transfer facility, two cell towers, and a municipal water tower were constructed within the immediate viewshed of the park. The oil tank farm expansion and truck-to-pipeline transfer facility just beyond the treetops would come into the immediate viewshed if a fire or wind event occurred. Additionally, there are wind farm developments being planned in the relatively near future just to the west of the Fort that gain increased feasibility with each passing quarter (T. Baker, personal communication, 14 July 2016).

4.1.6. Data Gaps

The views of and from Fort Laramie NHS are closely related to the primary purpose of the park unit. Continued assessments of important park views will be important to understand that potential stressors could impact visual resources of Fort Laramie NHS. In such assessments, NPS has opportunities to engage visitors in the monitoring process through the use of interactive viewshed signs. Visitors are likely to take photographs at important vantage points; if signs show specific reference points and present links to upload photographs via social media, visitors can contribute to ongoing 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 resources. 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.

Acknowledgements

- Mark Meyer (NPS)

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Google Earth. 2014b. Fort Laramie National Historic Site: Parade Grounds. 42°12’07”N, 104°33’30”W. Eye altitude: Ground level view.

Google Earth. 2014c. Fort Laramie National Historic Site: Park Entrance.42°12’19”N, 104°33’45”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, National Park Service 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, those areas existing in the absence of human-caused light at night, within the parks (NPS 2012c). 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 2012d) to 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 2012c). 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 United States 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 Fort Laramie NHS (Figure 4.2.1).

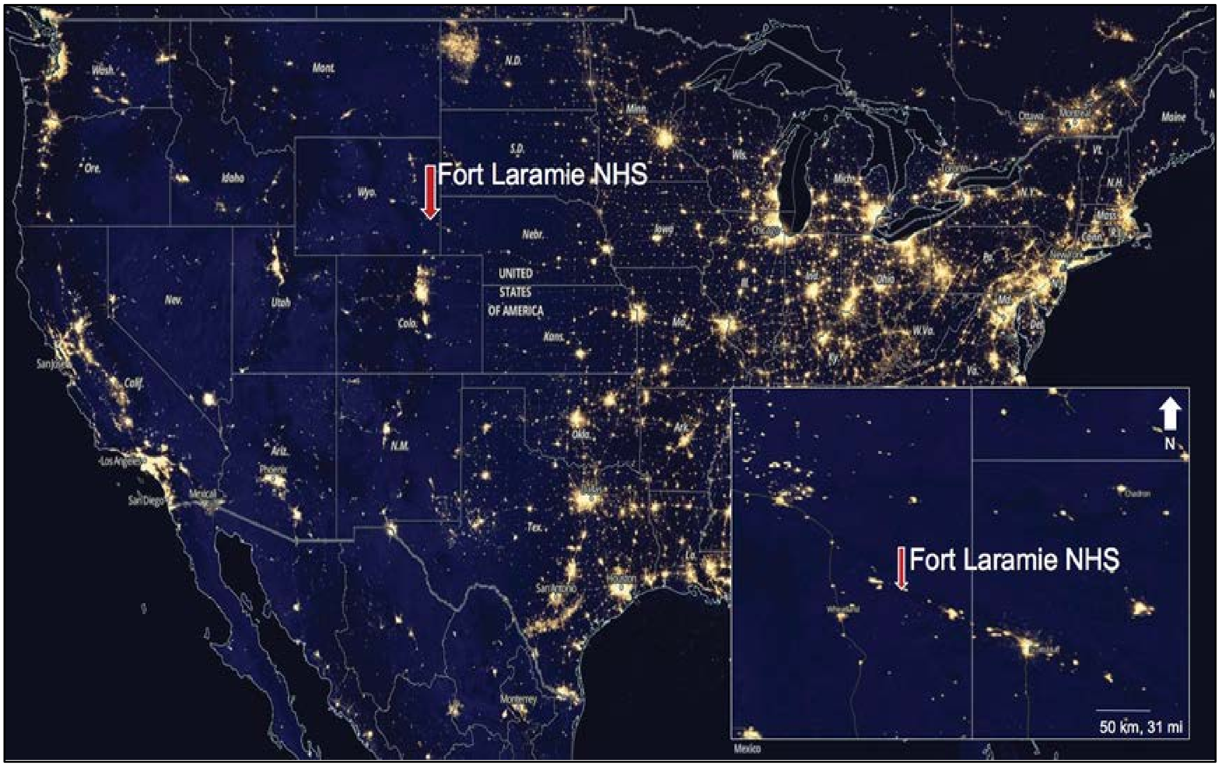


Figure 4.2.1. Satellite image of Fort Laramie NHS and the lower 48 states at night in 2012. Map generated at https://worldview.earthdata.nasa.gov using Earth at Night 2012 base layer from NASA Earth Observatory.

Night skies helped to guide early settlers, fur trappers, and traders to eastern Wyoming and Fort Laramie, and park visitors can still come to Fort Laramie NHS for stargazing experiences, albeit somewhat compromised by recent energy development facilities (T. Baker, personal communication, 11 August 2016). The 2016 Centennial Night Sky Event at Fort Laramie National Historic Site drew visitors for a guided tour to the stars and telescope observation of the sky. Since about 2006, star gazing events have been scheduled each summer at Fort Laramie NHS in July or early August on nights when the moon will not interfere with viewing deep sky objects (K. Jacobs, personal communication, 9 August 2016). These programs begin after dark and can go until midnight. Program instructors usually begin with a tutorial session on using star maps and a discussion of the constellations, planets, and deep sky objects that participants will observe. Some discussion of star lore from other cultures or current happenings in Astronomy is also often part of the program. In 2016, participants saw planets (Jupiter, Saturn, and Mars), Andromeda Galaxy, Whirlpool Galaxy, clusters, nebula, and other objects (K. Jacobs, personal communication, 9 August 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 NPS 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 2016b).

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 lightscapes in many NPS units (NPS 2012d). 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 Fort Laramie NHS.

<u>*Measure of Night Sky Quality: Bortle Dark Sky Scale*</u>

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 4.2.2). 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.	Zodiacal 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.
Class 4 Rural /suburban 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.

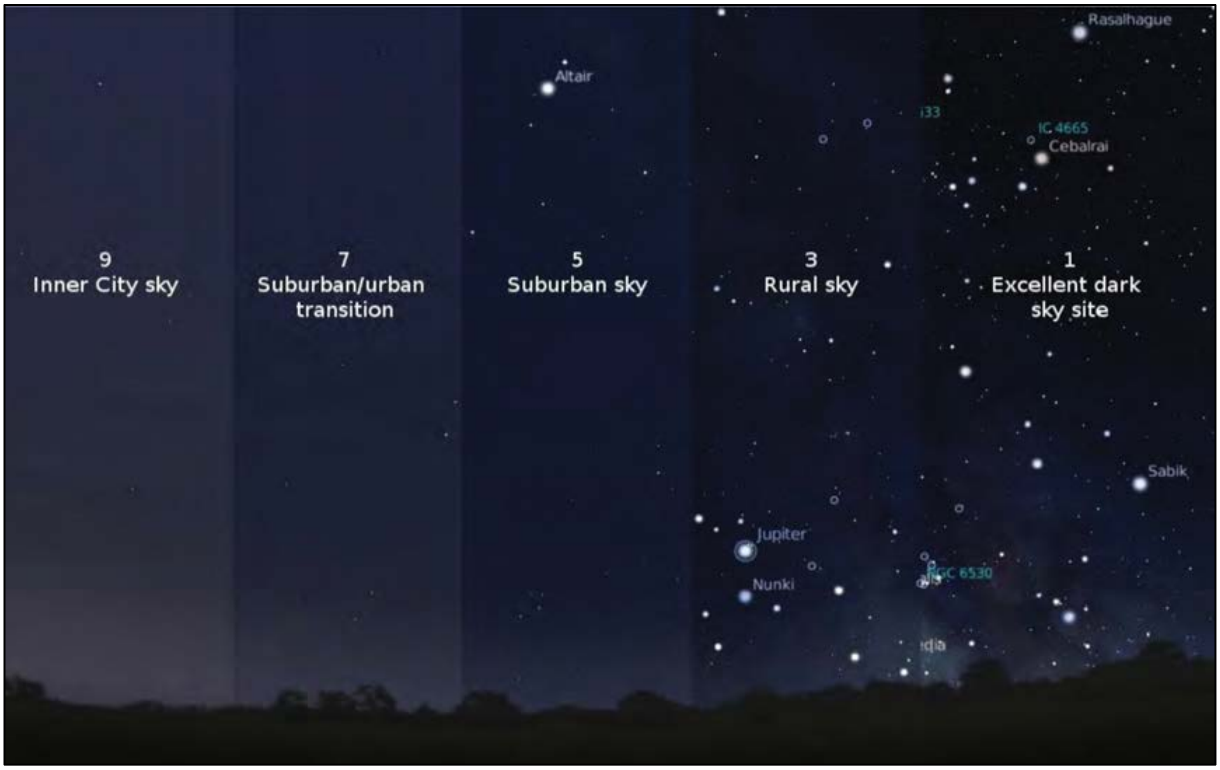


Figure 4.2.2. Bortle Dark-Sky composite image. Image from Struthers et al. (2014), generated from Stellarium (stellarium.org).

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		Bortle class
Warrants significant concern		7 – 9
Warrants moderate concern		4 – 6
Resource in good condition		1 – 3

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 assigned 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		Synthetic SQM values
Warrants significant concern	🔴	< 19.5
Warrants moderate concern	🟡	19.5 – 21.3
Resource in good condition	🟢	> 21.3

Measure of Night Sky Quality: Sky Quality Index (SQI)

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 from 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		SQI values
Warrants significant concern	🔴	< 60
Warrants moderate concern	🟡	60 ≤ and < 80
Resource in good condition	🟢	80 – 100

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 2012d). For these reasons, an important indicator to the Night Sky resource is the presence of natural nightscapes 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 Fort Laramie NHS, 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 Ratios 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 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		ALR values
Warrants significant concern	🔴	> 2.0
Warrants moderate concern	🟡	0.33 – 2.0
Resource in good condition	🟢	< 0.33

Data Sources

To assess the condition of night sky, we used data collected by NPS Natural Sounds and Night Skies Division May 2, 2013. These data were collected on site at Fort Laramie NHS 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

NPS guidelines, expert opinion and the scientific literature. We used a point system to assign indicators to categories. This point system is based on the NPS methods that were developed to calculate overall air quality condition, 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, covering a five-year time span 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

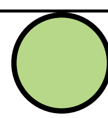
We used the general approach for combining indicator conditions described in Chapter 3 (Methods 3.2.2) to calculate overall resource condition (Table 4.2.6).

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	Warrants moderate concern	High	Not available	Bortle Dark Sky Class was 4, which placed the condition of this measure in the category, *Warrants Moderate Concern*. Monitoring was conducted on site, but only once at the time of this assessment, so confidence was *High* and trend was *Not Available*.
	Synthetic sky quality meter	Resource in good condition	High	Not available	Synthetic SQM was 21.71, which placed the condition of this measure in the category, *Resource in Good Condition*. Monitoring was conducted on site, but only once at the time of this assessment, so confidence was *High* and trend was *Not Available*.
	Sky quality index	Resource in good condition	High	Not available	Sky Quality Index was 82.6, which placed the condition of this measure in the category, *Resource in Good Condition*. Monitoring was conducted on site, but only once at the time of this assessment, so confidence was *High* and trend was *Not Available*.
Natural light environment	Anthropogenic light ratio	Warrants moderate concern	High	Not available	Anthropogenic Light Ratio was 0.49, which placed the condition of this measure in the category, *Warrants Moderate Concern*. Monitoring was conducted on site, but only once at the time of this assessment, 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 4 was in the category, *Warrants Moderate Concern*, but Sky Quality Index (82.6) and Synthetic SQM (21.7) were both in the category, *Resource in Good Condition*. The combined average among measures was 83, which placed the condition of Night Sky Quality at Fort Laramie NHS 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 Fort Laramie NHS, so confidence was *High*.

Trend

Data were available for only one date, so trend was *Not Available*.

<u>Natural Light Environment</u>

Condition: Warrants Moderate Concern
Confidence High
Trend: Not Available

Condition

The ALR rating of 0.49 at Fort Laramie NHS was in the category, *Warrants Moderate Concern*. Anthropogenic Light Ratio was the only measure of the indicator, Natural Light Environment, so this indicator was in the category, *Warrants Moderate Concern*.

Confidence

Natural Light Environment data were collected by the NPS Natural Sounds and Night Skies Division conducted on site at Fort Laramie NHS, so confidence was *High*.

Trend

Data were available for only one date, so trend was *Not Available*.

<u>Night Sky Overall Condition</u>

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)	
Natural light environment	• Anthropogenic Light Ratio (ALR)	
Overall condition for all indicators and measures		

Condition

The scores alone indicated the condition of Fort Laramie NHS was in *Resource in Good Condition*, but expert opinion of managers on site moved the condition to *Warrants Moderate Concern* based on observations in the time since the night sky sampling was completed.

Confidence

The condition was moved to a lower category based on qualitative assessment. Confidence was *Medium*.

Trend

The trend was identified based on a qualitative assessment that condition had deteriorated. Trend was *Deteriorating*.

4.2.5. Stressors

Threats to night sky condition at Fort Laramie NHS include the Guernsey rail facility and tank farms, which emit a glow visible from the park unit, the pipeline-to-rail transfer facility near to the park, strobe(s) on the town's municipal water tower, and other tank farms and truck-to-pipeline facilities in the broader area surrounding the Fort. The pipeline-to-rail transfer facility near to the park has, however, employed deflectors to keep the light projected towards the ground that, at the time of this assessment, probably decrease light pollution around Fort Laramie NHS. The light(s) on the municipal water tower is directed mostly away from the Fort, and it switches to a red light from dusk to dawn. There is also a communication tower in the town of Fort Laramie, with a strobe that pulses constantly (M. Evans, personal communication, 9 September 2016). The railroad yard in Guernsey produces a large glow on the horizon to the northwest that shows up in night sky viewing. The glow of Wheatland, Torrington/Scottsbluff, Cheyenne, and the front range of Colorado are also visible on the horizon (M. Evans, personal communication, 9 September 2016).

4.2.6. Data Gaps

The most recent data were collected in 2013, 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 Fort Laramie NHS would improve the ability of managers to assess these conditions and develop strategies to maintain optimal night sky conditions.

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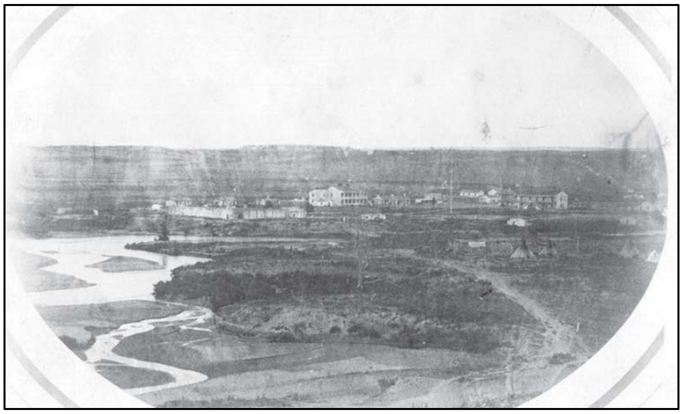
4.3. Soundscape/Acoustic Environment

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 Fort Laramie National Historic Site and reorganized several subsections herein to follow the structure that we used for the other NRCA natural resource sections.



The sources of noise around what is now Fort Laramie NHS have changed since this image was taken in 1858 (Photo: Historic photo, 1858).

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 (§ 4.9) 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

Fort Laramie NHS is surrounded by agricultural operations and roads, and located less than two kilometers (1.2 miles) west of the small town of Fort Laramie.

Primary sources of non-natural sounds within the park include 3–4 coal/oil trains per hour, operations at the oil transfer facilities, automobile traffic, visitor conversations and associated acoustics, maintenance operations, agricultural activities, and air traffic passing overhead (T. Baker, personal communication, 11 July 2016).

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 (Templeton 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 6dB 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.

The natural acoustic environment is vital to the function and character of a national park. Natural sounds 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

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, 100 m above ground level	Yukon-Charley Rivers NP
126	Cannon fire at 150 m	Vicksburg NMP

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).

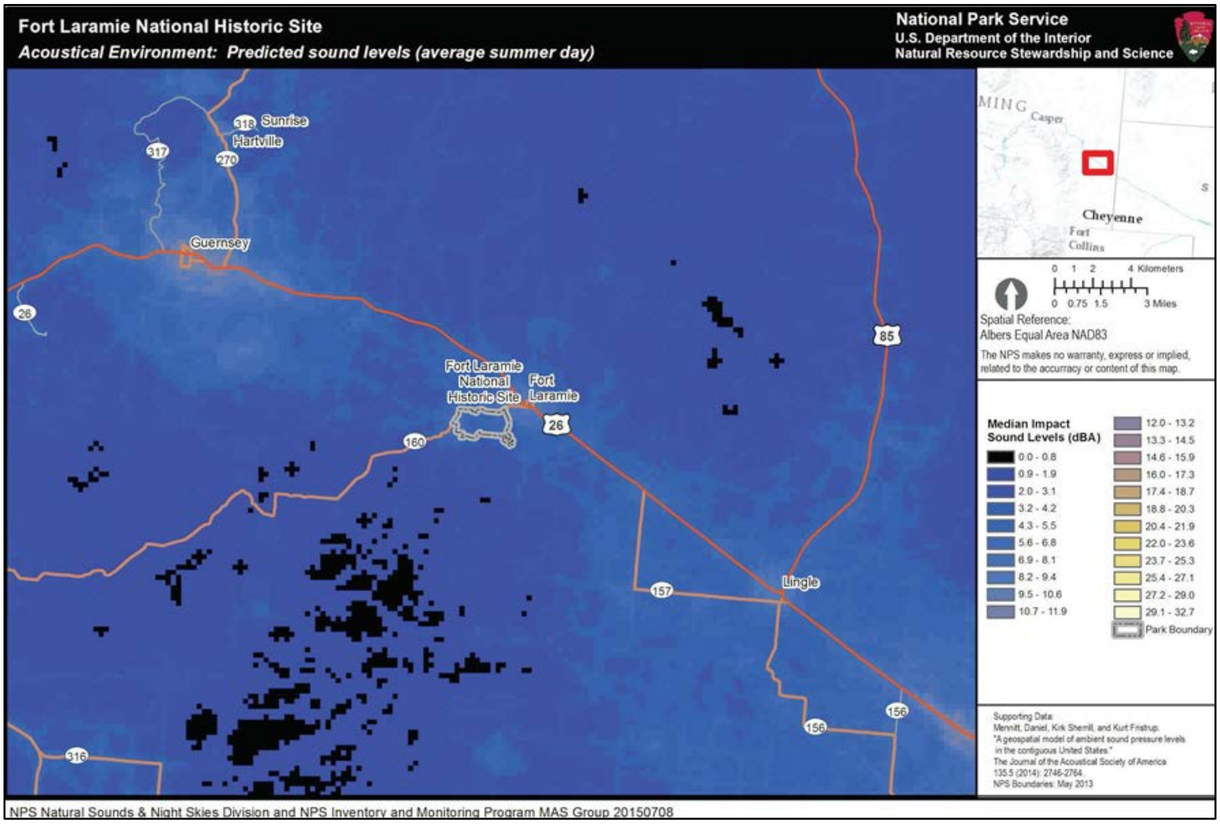


Figure 4.3.1. Modeled L_{50} dBA impact levels in Fort Laramie NHS (NPS 2013).

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, where 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 (US 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* are lower for these park units than for units near urban areas. Urban areas tend to have higher ambient sound levels than non-urban areas (U.S. EPA 1971, Schomer et al. 2011). Higher thresholds are used for parks in urban areas. However, acoustic environments are important in all parks; units in urban areas may seek to preserve or restore low ambient sound levels to offer respite for visitors. We used non-urban threshold to identify condition of anthropogenic impact in Fort Laramie NHS.

Table 4.3.2. Soundscape/acoustic environment condition categories for anthropogenic impact.

Resource condition		Mean L_{50} impact (dBA) non-urban
Warrants significant concern	(red circle)	dBA > 3.0 Listening area reduced by > 50%
Warrants moderate concern	(yellow circle)	1.5< dBA ≤ 3.0 Listening area reduced by 30–50%
Resource in good condition	(green circle)	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 Fort Laramie NHS.

Quantifying Soundscape/Acoustic Environment Condition, Confidence, and Trend

Indicator Condition

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 Condition, Confidence, and Trends

<u>Soundscape/Acoustic Environment Overall Condition</u>

Table 4.3.3. Soundscape/acoustic environment overall condition.

Indicators	Measures	Condition
Anthropogenic impact	• L_{50} dBA impact • Qualitative assessment	

Condition

The L_{50} dBA impact level at Fort Laramie NHS was 5.0, which placed overall condition for soundscape at Fort Laramie NHS in the category, *Warrants Significant Concern*.

Park managers agreed with this condition and identified specific stressors on the soundscape.

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 Fort Laramie NHS were insufficient to calculate a trend. Trend was *Not Available*.

4.3.5. Stressors

A common source of noise in national parks is transportation (i.e., airplanes, vehicles). 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/1981_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).

Fort Laramie NHS is surrounded by agricultural operations and roads, and is located less than two kilometers (1.2 miles) west of the small town of Fort Laramie. Primary sources of non-natural sounds within the park include 3–4 coal/oil trains per hour, operations at the oil transfer facilities, automobile traffic, visitor conversations and associated acoustics, maintenance operations, agricultural activities, and air traffic passing overhead.

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.

Acknowledgements

- 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 Fort Laramie NHS. 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 over Fort Laramie NHS (Photo: SPBer, Wikimedia Commons 2014).

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 § 7401 et 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 Fort Laramie NHS, 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).

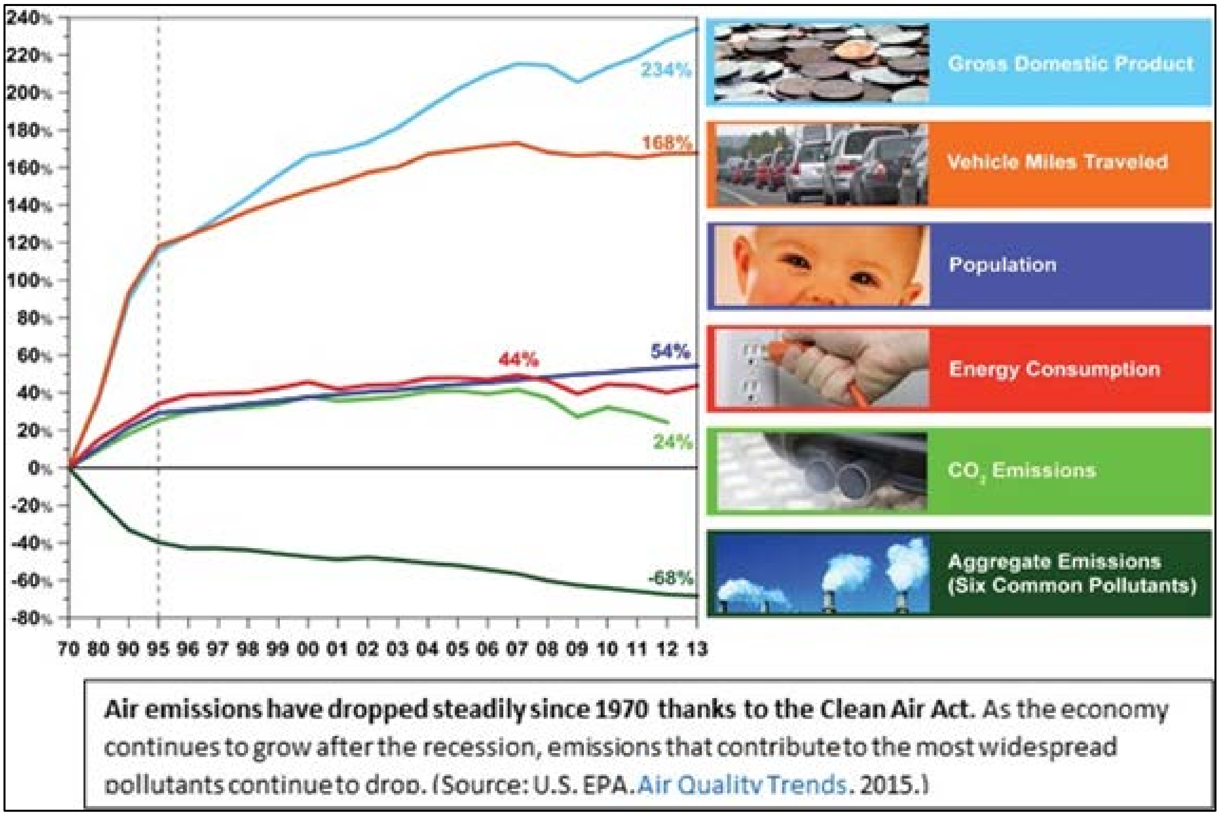


Figure 4.4.1. Air quality trends for the United States from 1970 to 2013. Emissions that contribute to poor air quality in the United States have declined substantially since 1970, in spite of economic and population growth (Figure courtesy of EPA http://www.epa.gov/airtrends/aqtrends.html#comparison).

The American Lung Association (ALA) compiles a State of the Air report for each state, and assigns scores for air quality by county. Fort Laramie NHS is located in Goshen County where there were not enough monitoring data from 2014–2015 to assign a score, but adjacent Laramie County received the highest possible grade (A) for that time period (ALA 2015). There is, however, significant heterogeneity in air quality within the region. During the same time period, Sublette County, which is 350 kilometers west of Goshen, received the lowest possible grade (F) due to ozone and particulate pollution. The disparity in these grades within Wyoming highlights the importance of identifying air quality conditions at as local a level as possible.

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 2016). 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, d). 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.

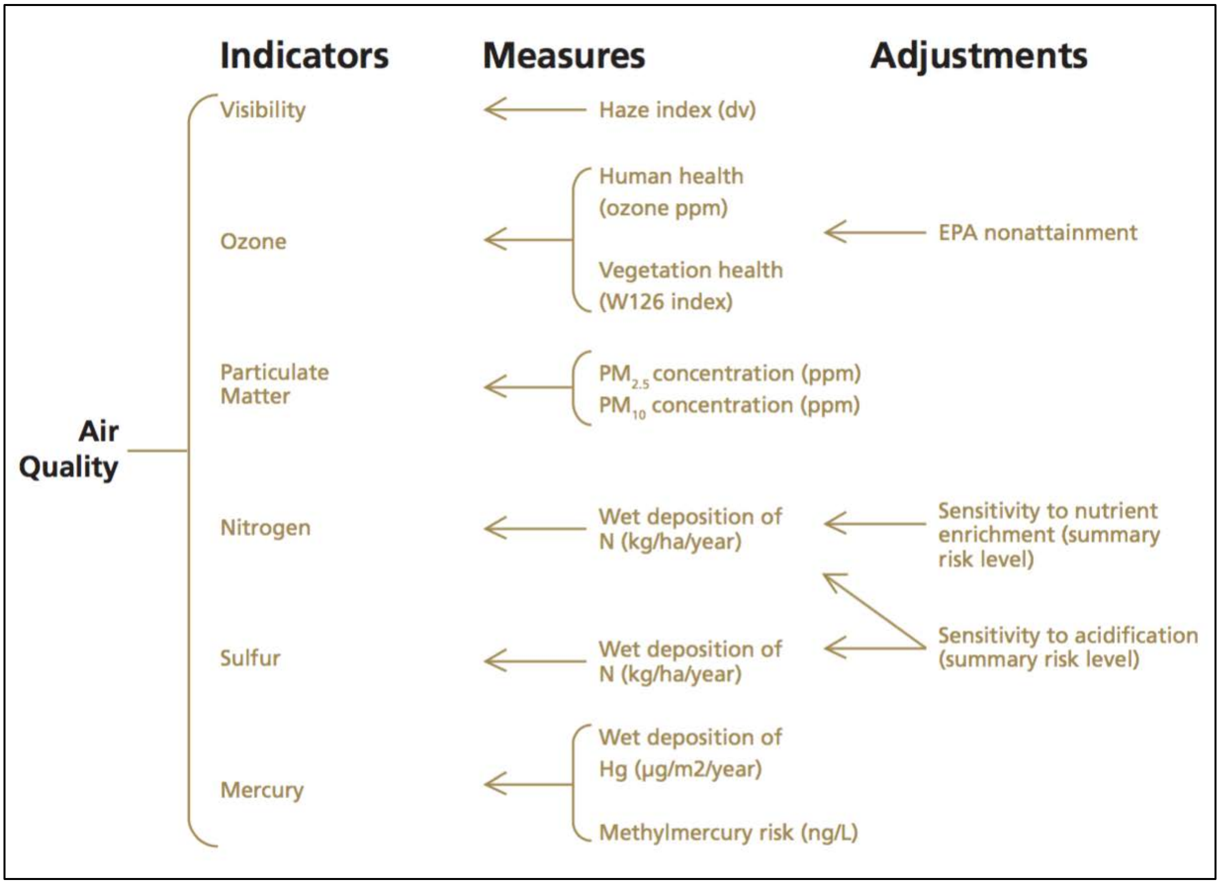


Figure 4.4.2. Schematic of the factors considered in air quality condition assessment.

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.

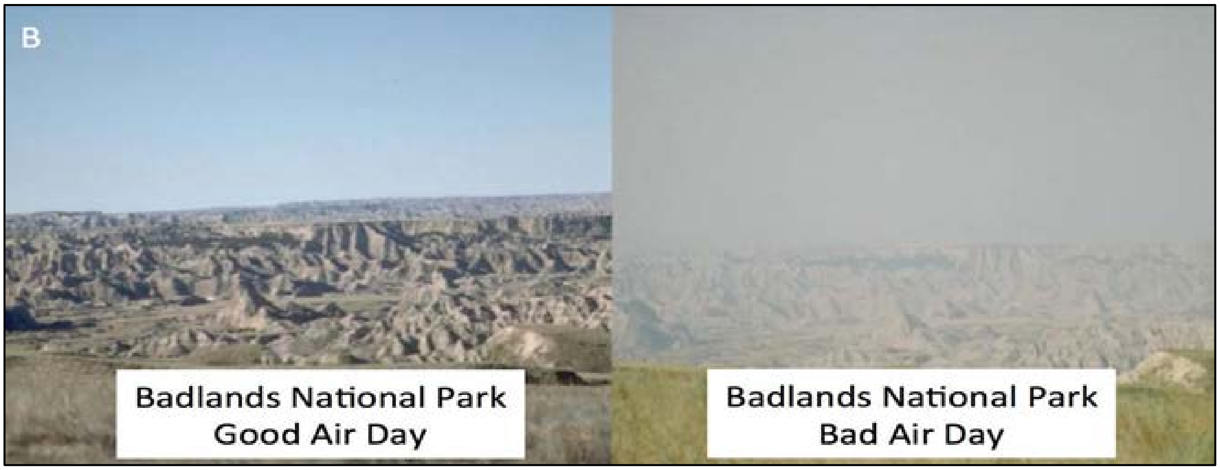


Figure 4.4.3. Photo representation of air quality in Badlands NP for a good air and bad air day. Haze can reduce visibility at Fort Laramie NHS and may be accompanied by an increased risk to human and environmental health. Fires and dust storms can contribute to poor air quality days, such as this one at Badlands NP (Photo: NPS-ARD 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. Fort Laramie NHS 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 Fort Laramie NHS boundary is reported as the visibility condition from this national analysis and compared to NPS-ARD benchmarks (Table 4.4.1).

Table 4.4.1. Air quality condition categories for visibility condition (NPS-ARD 2015a).

Resource condition		Visibility* (dv)
Warrants significant concern		> 8
Warrants moderate concern		2 – 8
Resource in good condition		< 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 2016), 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 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), volatile organic compounds (VOCs), or carbon in the presence of sunlight. On hot, sunny days, the right combination of these compounds can combine to form ozone (Figure 4.4.4).

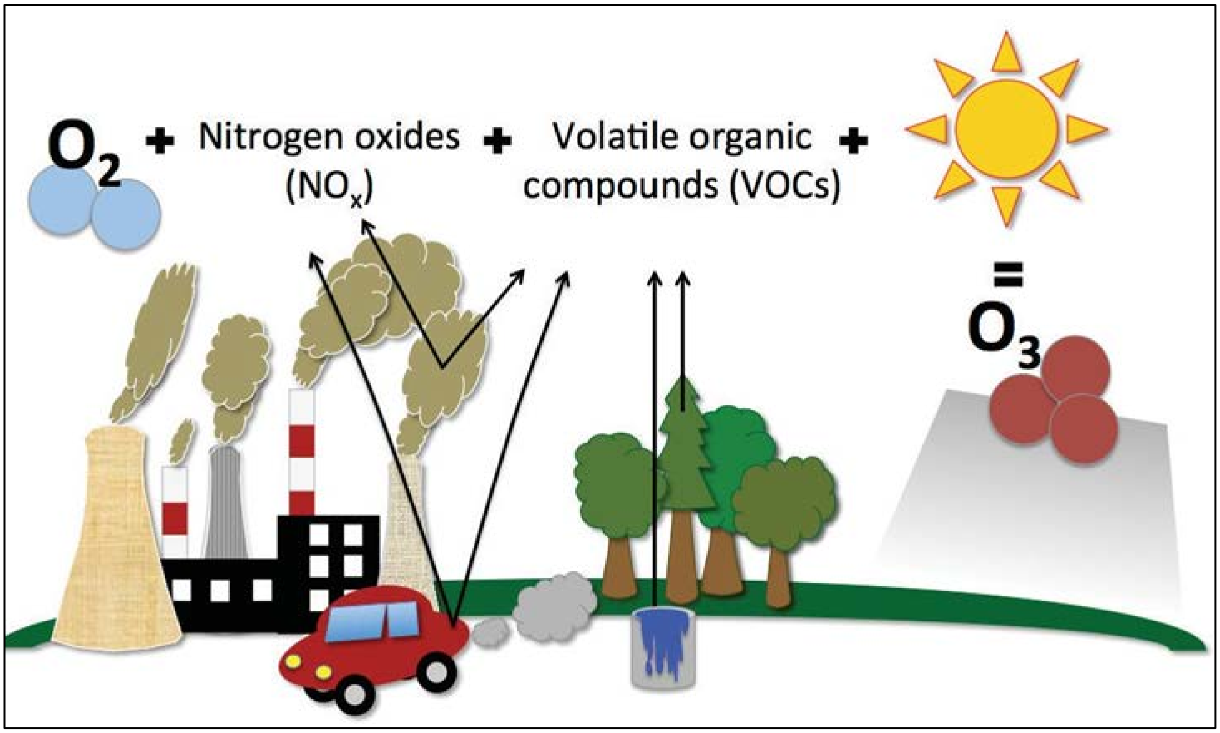


Figure 4.4.4. Graphic illustrating ozone (O_3) production (Dibner 2017). Ozone is formed when oxygen (O_2) combines with nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in the presence of sunlight. Fuel combustion from vehicles, power plants, and industrial operations produces NO_x and VOCs. 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.

While VOCs are produced naturally by some plants and soil microbes (Insam and Seewald 2010), additional VOCs are emitted from 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).

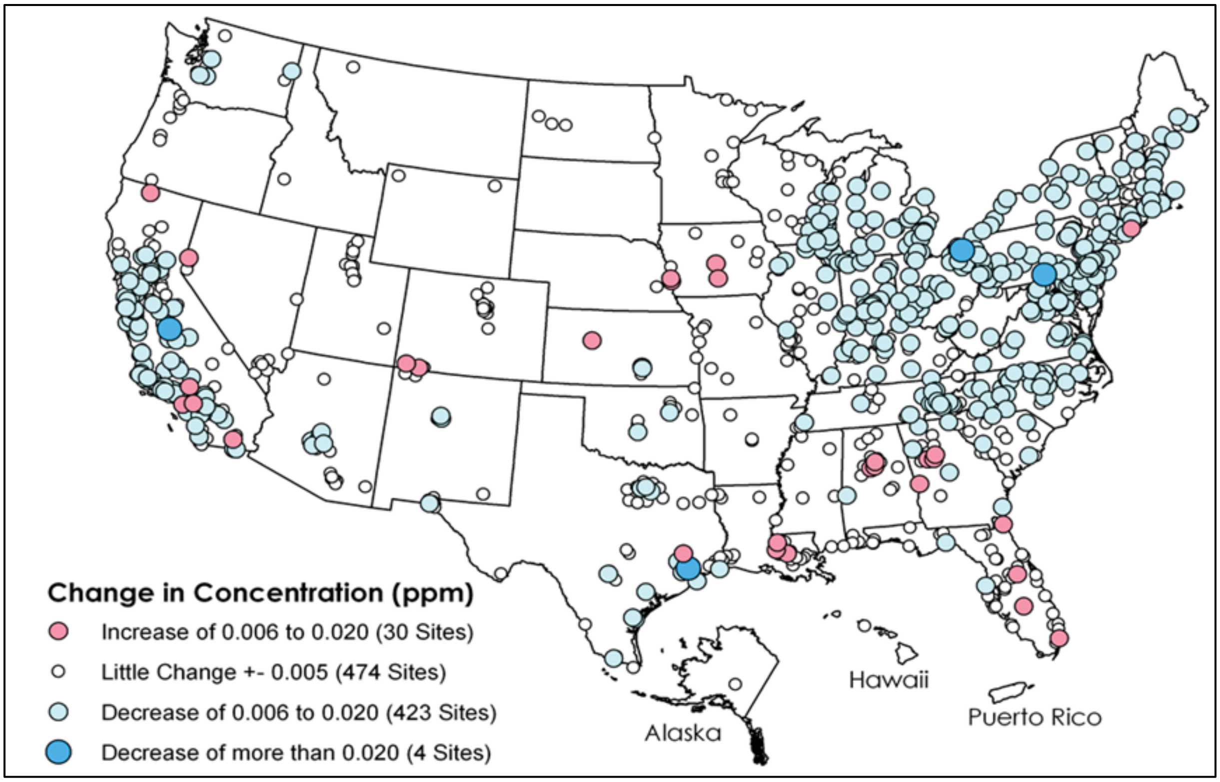


Figure 4.4.5. Change in ozone concentrations for the US from 2001 to 2007 (EPA 2008).

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 Fort Laramie NHS 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 4.4.2).

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

Resource condition		Ozone concentration* (ppb)
Warrants significant concern		≥ 71
Warrants moderate concern		55 – 70
Resource in good condition		≤ 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.

Figure 4.4.6. Foliar plant damage as a result of high ambient levels of ozone (Photo: USDA ARS).

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).

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 Fort Laramie NHS 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 4.4.3).

Table 4.4.3. Air quality condition categories for W126 indices (NPS-ARD 2015a).

Resource condition		W126* (ppm-hrs)
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 (Stölzel 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 standard for $PM_{2.5}$ is micrograms per cubic meter (µg/m^3) annually (3-year average of weighted annual mean) and 35 µg/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 4.4.4).

Table 4.4.4. 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)**
Warrants significant concern	🔴	≥ 35.5	≥ 155
Warrants moderate concern	🟡	12.1 – 35.4	55 – 154
Resource in good condition	🟢	≤ 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 4.4.4). 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).

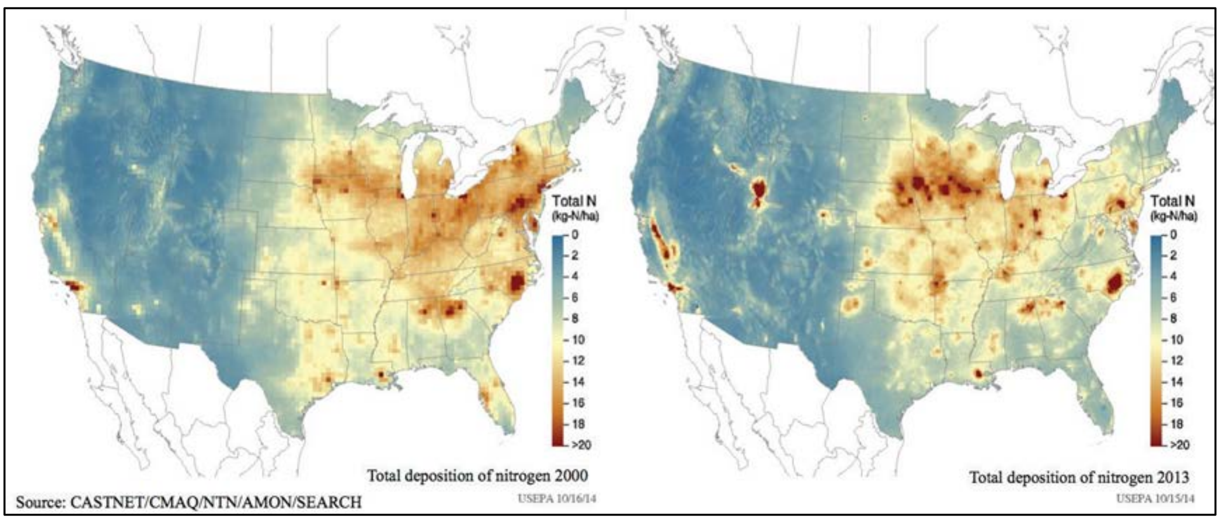


Figure 4.4.7. Total nitrogen deposition for the United States for 2000 and 2013. Total nitrogen deposition has decreased in some parts of the United States and increased in others.

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)

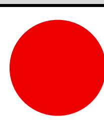
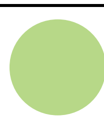
Wet deposition is the most common and simplest way to measure deposition of nitrogen. Dry deposition data for nitrogen is difficult to obtain because dry deposition is not measured directly (Mickler et al. 2000; Freedman 2013). Wet deposition of nitrogen is measured in kilograms per hectare per year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

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 Fort Laramie NHS.

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 4.4.5). 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 4.4.5. Air quality condition categories for wet deposition (NPS-ARD 2015a).

Resource condition		Wet deposition* (kg/ha/yr)
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 Fort Laramie NHS 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: Sulfur Deposition

Like nitrogen, sulfur (S) is an acidifying compound that can be transported out of the atmosphere as acid rain. The deposition of S-compounds can acidify water and soil (Likens et al. 1996).

Measure of Sulfur Deposition: Wet Deposition of S (kg/ha/yr)

Wet deposition is the most common and simplest way to measure deposition of sulfur. Dry deposition data of sulfur is difficult to obtain because it can’t be measured directly (Mickler et al. 2000, Freedman 2013). Wet deposition of sulfur is measured in kilograms per hectare per year (kg/ha/yr) (Table 4.4.5).

Sulfur wet deposition is monitored across the United States as part of the NADP/NTN. Wet deposition was calculated by multiplying sulfur (from sulfate) concentrations in precipitation by a normalized precipitation. Annual wet deposition is averaged over a 5-year period at monitoring sites with at least 3 years of annual data. Five-year averages are then interpolated across 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 sulfur, 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 sulfur levels were calculated from interpolated data (NPS-ARD 2015b), using monitoring sites that were not on site at Fort Laramie NHS.

NPS-ARD selected a wet sulfur deposition threshold of 1.0 kg/ha/yr (see rationale in the section on nitrogen). A value greater than 3 kg/ha/yr is assigned a *Warrants Significant Concern* status. A value from 1–3 kg/ha/yr is assigned *Warrants Moderate Concern* status. *Resource in Good Condition* if the current sulfur condition is less than less than 1 kg/ha/yr (Table 4.4.5).

Condition Adjustment: Sulfur Deposition

If Fort Laramie NHS was at a very high risk for acidification, the condition for sulfur deposition was adjusted to the next worse category.

To assess park risk of acidification we used a risk assessment conducted by Sullivan et al. (2011b) that combined measures of pollutant exposure, ecosystem sensitivity and park protection to calculate a summary risk. If the park was assigned very high risk, we adjusted the condition 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-caused sources 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 4.4.6).

Table 4.4.6. 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 4.4.7).

Table 4.4.7. 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 4.4.8) to identify one of three park-specific mercury/toxics status categories: *Resource in Good Condition*, *Warrants Significant Concern*, or *Warrants Significant Concern*.

Table 4.4.8. Mercury condition assessment matrix (NPS-ARD 2015a).

Predicted methylmercury concentration rating	Mercury wet deposition rating				
	Very low	Low	Moderate	High	Very high
Very low					
Low					
Moderate					
High					
Very high					

Note: Condition is represented in the following manner; green = good, yellow = moderate, red = significant concern.

Condition Adjustment: Mercury Deposition

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

Indicator Condition

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 4.4.9); 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).

Table 4.4.9. Air quality overall condition categories.

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

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.

4.4.4. Air Quality Condition, Confidence, and Trends

Visibility

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

Condition

The Haze Index for 2009–2013 was 4.4 dv, which placed visibility for Fort Laramie NHS in the *Warrants Moderate Concern* category.

Confidence

Visibility was calculated from interpolated data (NPS-ARD 2013b), necessarily using monitoring data from more than 100 kilometers away. Because none of those monitoring stations were on-site in Fort Laramie NHS or within 100 kilometers (NPS-ARD 2015a), the confidence was *Medium*.

Trend

The closest IMPROVE monitoring site was over 150 miles away, so we could not calculate trend (NPS-ARD 2013a). Trend was *Not Available*.

<u>Ozone</u>

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

Condition

Human health condition: The calculated ground-level ozone concentration from 2005–2009 was 67.3 ppb, which placed ozone pollution at Fort Laramie NHS in the *Warrants Moderate Concern* category.

Vegetation health condition: The W126 value for Fort Laramie NHS was 10.9 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 Fort Laramie NHS (Kohut 2004). Ozone-sensitive plants were present (Table 4.4.10), but the observed levels of ozone were unlikely to damage plants. The low rating for risk of foliar damage meant the condition for ozone pollution remained in the *Warrants Moderate Concern* category.

Table 4.4.10. Ozone-sensitive plants at Fort Laramie NHS.

Family	Scientific name	Common name
Oleaceae	*Fraxinus pennsylvanica*	Green ash
Pinaceae	*Pinus ponderosa*	Ponderosa pine
Anacardiaceae	*Rhus trilobata*	Skunkbush

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 Fort Laramie NHS, so a trend for ozone was *Not Available*.

Particulate Matter

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

Condition

Fort Laramie is located in Goshen County, Wyoming, 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 Fort Laramie NHS was 11.7 $\mu g/m^3$, which falls in the *Resource in Good Condition* category. PM_{10} concentration was 19.4 $\mu g/m^3$ for 2011–2013, which mean that the resource is in good condition. The overall particulate matter condition falls into the *Resource in Good Condition* category.

Confidence

The particulate matter condition was calculated from a $PM_{2.5}$ monitors located within Fort Laramie NHS, but the PM_{10} data were collected at monitors not located within the park. Confidence was *Medium*.

Trend

Trend was *Not Available*.

Nitrogen Deposition

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

Condition

The total N wet deposition level from 2009–2013 was 1.5 kg/ha, which placed total N wet deposition pollution at Fort Laramie NHS 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 Fort Laramie NHS for susceptibility to acidification and eutrophication. Fort Laramie NHS was at Moderate risk for acidification from N deposition (Sullivan et al. 2011b) and low risk for nutrient enrichment from N deposition (Sullivan et al. 2011a), so Nitrogen at Fort Laramie NHS remained in the *Warrants Moderate Concern* category.

Confidence

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

Trend

The closest monitoring site for wet deposition was approximately 85 kilometers northwest in away in Douglas, WY. The maximum distance allowed for calculating a trend in wet N or 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>Sulfur Deposition</u>

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

Condition

The total S wet deposition from 2009–2013 was 0.5 kg/ha, which placed S wet deposition pollution at Fort Laramie NHS 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. Fort Laramie NHS was at low risk for acidification from S deposition (Sullivan et al. 2011b), so sulfur at Fort Laramie NHS 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 85 kilometers away in Douglas, WY. 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 2013). Trend was *Not Available*.

<u>Mercury Deposition</u>

Condition: Warrants Moderate Concern 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 2012– 2014 estimated wet mercury deposition is low at the park, at 5.2 μg/m^2/yr (K. Taylor, personal communication, 26 May 2016).

The predicted methylmercury concentration in park surface waters is high, estimated at 0.1 ng/L (USGS 2015). Wet deposition and predicted methylmercury ratings were combined to determine the *Warrants Moderate Concern* condition.

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

Table 4.4.11. 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/yr)	
Sulfur	• Wet deposition (kg/ha/yr)	
Mercury	• Wet deposition (μg/m^2/yr) • Methylmercury risk	
Overall condition for all indicators and measures		

The overall air quality condition 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 (NPS-ARD 2015a). The total score for overall air quality condition was 50 points, which placed Fort Laramie NHS in the *Warrants Moderate Concern* category.

Confidence

Confidence was *High* for Visibility 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*.

4.4.5. Stressors

Potential air quality stressors include the Laramie River Station, a coal-fired power plant 28 kilometers southeast of Fort Laramie NHS, smoke from fires during the summer months, and oil and gas development to the south and northwest. Emissions from the power plant and wells likely contribute to impaired visibility and high ozone production in the area (Karion et al. 2013).

Fort Laramie NHS is located just outside of three major oil and gas basins. The Powder River Basin (PRB) is the closest, located to the north of the Fort Laramie NHS in eastern Wyoming, southwestern South Dakota, and southeastern Montana. The Denver-Julesburg is located to the south of Fort Laramie NHS in north eastern Colorado, and the Williston Basin is located to the north of Fort Laramie NHS 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 Fort Laramie NHS 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 Fort Laramie NHS over time.

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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 for water and nutrient cycles, and numerous recreational opportunities. Surface waters are also aesthetic resources and 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 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 2006).

Laramie River at Fort Laramie NHS (Photo: Decumanus 2004).

Regional Context and Trend

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).

Fort Laramie NHS is located in southeast Wyoming at the confluence of the Laramie and North Platte Rivers, which eventually flow east into the Missouri River.

The Laramie River is a prominent natural feature that bisects the park unit and is an important resource for plants and wildlife in the region. The North Platte River that bounds Fort Laramie NHS on the east side is larger than the Laramie River, but the section of Laramie River that winds through the park unit is a higher regional priority for NPS (Wilson et al. 2014).

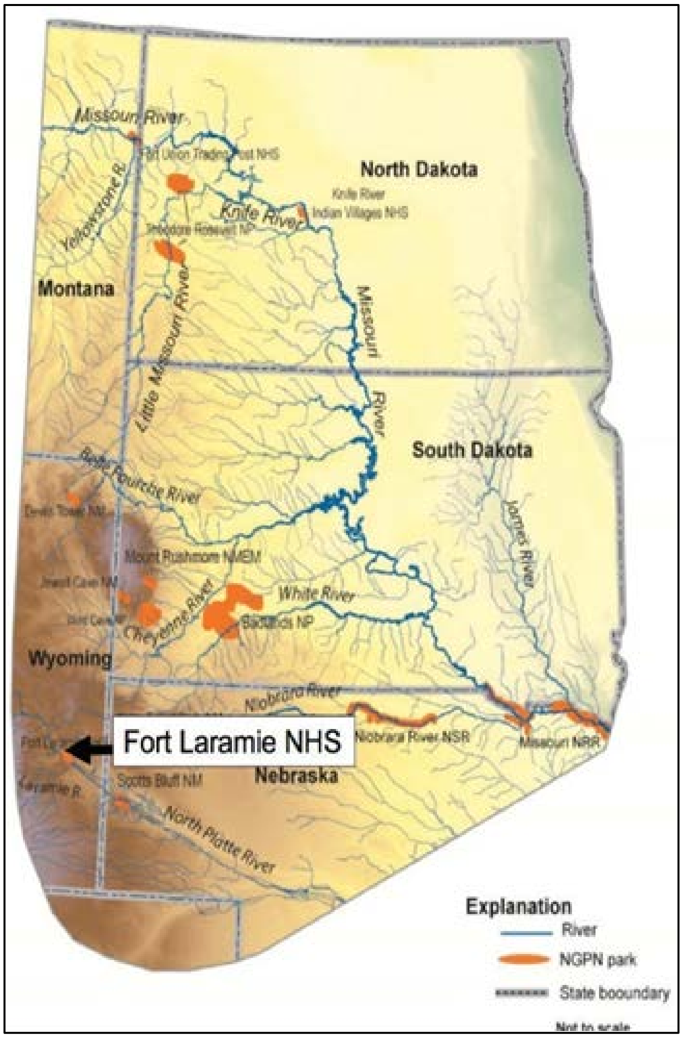


Figure 4.5.1. Tributaries and rivers in Northern Great Plains Network (NGPN) park units (Wilson et al. 2014).

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 Laramie River that runs through Fort Laramie NHS is a high priority for NGPN compared to other rivers and tributaries in the NPS network (Wilson et al. 2014). The Laramie River in Fort Laramie NHS has the designation as a 2AB surface water, which means that it is a cold water game fishery with the following designated uses: drinking water, fish (cold water game, nongame, consumption), non-fish aquatic life, recreation, wildlife, industry, agriculture, and scenic value (WY DEQ 2013, Wyoming Statutes § 35-11-101 through 35-11-1803).

The river is designated for primary contact recreation, which includes all activities in which visitors could be fully immersed in water or ingest water (e.g., swimming, water skiing, jet skiing). Adherence to this designation should also protect visitors from exposure to unsafe levels of bacteria. The North Platte River, which bounds the east edge of the park unit, is also a 2AB river. The smaller Deer Creek, a tributary to the Laramie River on the south side of Fort Laramie NHS, is designated as a 2C surface water; surface waters of this class do not have designated drinking water or cold water game fish uses, but otherwise have the same uses as 2AB surface waters.

Some water quality standards vary with season and aquatic life stages, particularly to protect spawning stages of fish species. In Wyoming, water quality standards depend on the stream classification, and exceedances of these criteria should be attributable to anthropogenic causes (WY DEQ 2013, Wyoming Statutes § 35-11-101–35-11-1803). All Wyoming surface waters are designated hierarchical for different types of use. Class 1 waters must meet the most stringent standards for water quality; Class 2 waters are regulated to support aquatic life and drinking water, though the type of aquatic life to which the standard is tailored varies among five subcategories (A–D) of these waters; Class 3 waters support aquatic life other than fish, such as invertebrates, amphibians, other vertebrates, and plants at some stage of their life cycles; Class 4 waters are regulated to support agriculture, industry, (non-aquatic) wildlife, and recreation. Surface waters with a Class 2AB Coldwater designation, like the Laramie and North Platte Rivers, and Class 2C designation, like Deer Creek, are regulated to the following water quality standards for pH, dissolved oxygen (Table 4.5.1), temperature, turbidity, and E.coli (WY DEQ 2013, Wyoming Statutes § 35-11-101–35-11-1803, L. Patterson, personal communication, 10 December 2015):

- **pH:** 6.5–9.0
- **Temperature:** ≤ 20°C and, within mixing zones, < 1.1°C difference from the natural background temperature outside of mixing zone for cold water fisheries of class 2AB water, like the Laramie and North Platte Rivers; this change in water temperature must be attributable to human activity. For 2C waters, like Deer Creek, change in temperature must be < 2.2°C
- **Turbidity:** Turbidity must not increase by > 10 Nephelometric Turbidity Units (NTUs) due to human activities in 2AB and 2C waters. The criteria for turbidity depend on an anthropogenic

cause for any increase in cloudiness or haziness, as well as good measurements of background turbidity.

- ***Escherichia coli (E. coli)*:** 60-day geometric mean concentration < 126 colony forming units/100 milliliters in primary contact waters during summer recreation season (May 1–September 30). The maximum allowed value for a single sample during the summer recreation season is < 576 colony forming units/100 milliliters where full body contact is infrequent, < 235 colony forming units/100 milliliters in high use swimming areas.
- **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 rate (Wyoming Statutes § 35-11-101–35-11-1803). Streamflow is the amount of water that flows in a river or stream, eventually reaching the ocean. 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).

Table 4.5.1. Dissolved oxygen (DO) criteria by date

Value calculation	Early life stages* (mg/l) for 2AB classes	Other life stages (mg/l) for 2AB classes	Early life stages* (mg/l) for 2C classes	Other life stages (mg/l) for 2C classes
One day minimum	≥ 8.0	≥ 4.0	≥ 5.0	≥ 3.0
Seven day mean	≥ 9.5	NA	≥ 6.0	NA
Seven day mean minimum	NA	≥ 5.0	NA	≥ 4.0
30 day mean	≥ 6.5	NA	NA	≥ 5.5

* Seasonal variation protects early life stages of cold water fish including embryonic and larval stages, as well as juveniles up to 30 days after hatching.

The flow regime is different in every river, 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 2AB streams in Wyoming, such as the Laramie and North Platte Rivers, water quality standards apply to surface waters at all times unless in a low flow; this critical flow point can be calculated using a minimum seven consecutive day flow, according to EPA methods, or by using another rigorous method (Wyoming Statutes § 35-11 101–1803). During low flow conditions, Wyoming Game and Fish provides guidance on how best to protect wildlife.

For Coldwater Class 2AB streams in Wyoming, such as the Laramie and North Platte Rivers, numeric water quality standards apply at all times except during low flow, as calculated above. During low flow conditions, WDEQ may, in consultation with the Wyoming Game and Fish Department and the affected discharger(s), require permittees to institute operational modifications to ensure the protection of aquatic life (Wyoming Statutes § 35-11 101–1803). This specification should not be interpreted as requiring the maintenance of any particular stream flow.

4.5.3. Methods

Indicators and Measures

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 regulated by the Wyoming Department of Environmental Quality (Wyoming Statutes § 35-11 101–1803) and/or identified as key indicators by NPS (Wilson et al. 2014). The NPS requires that each network monitor core parameters (DO, pH, specific conductivity, and 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.

As of 2014 no park units 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 Fort Laramie NHS and focused the most recent data available for each indicator. To assign a condition to each water quality indicator, we used measurements specified by Wyoming Department of Environmental Quality (Wyoming Statutes § 35-11 101–1803) and EPA. For indicators not regulated federally or by Wyoming DEQ, we relied on expert opinion. We assigned to each indicator one of three condition categories based on NPS water quality monitoring protocol (Wilson and Wilson 2014).

Potential 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 Wyoming standards for water quality. We then considered all indicator conditions together in an overall water quality condition assessment.

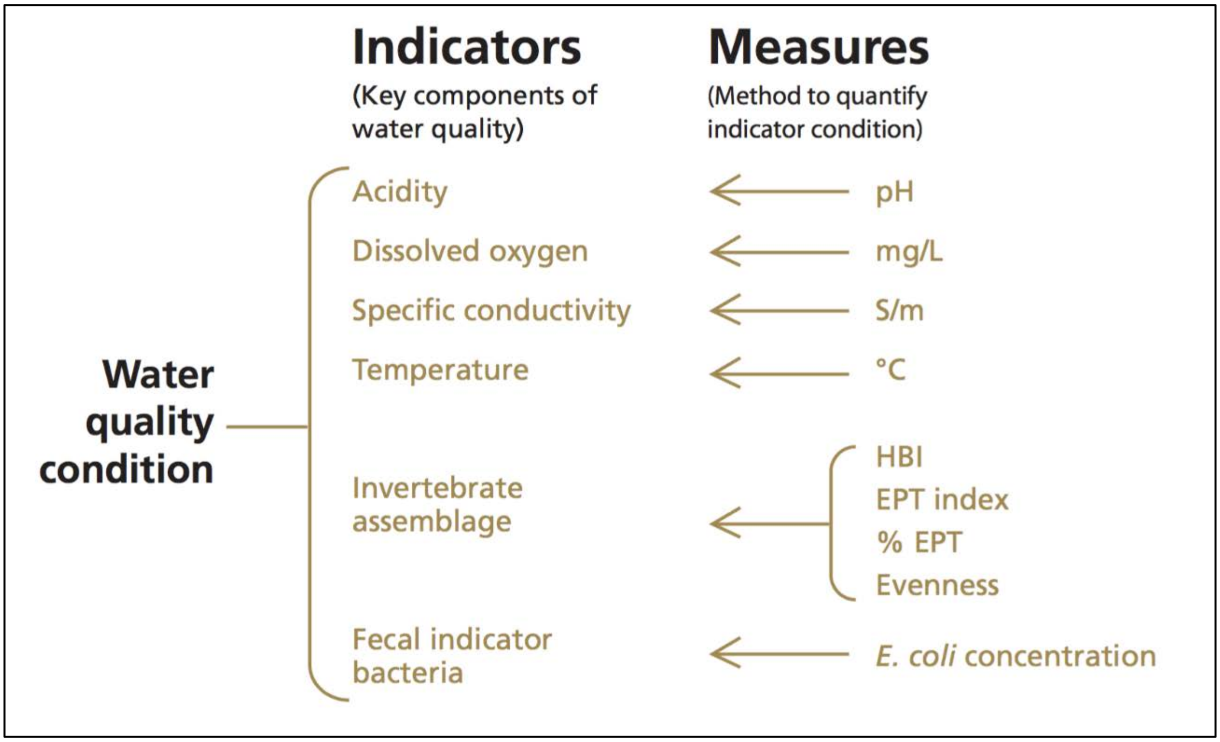


Figure 4.5.2. Schematic of the factors considered in water quality condition assessment.

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

Resource condition		% 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).

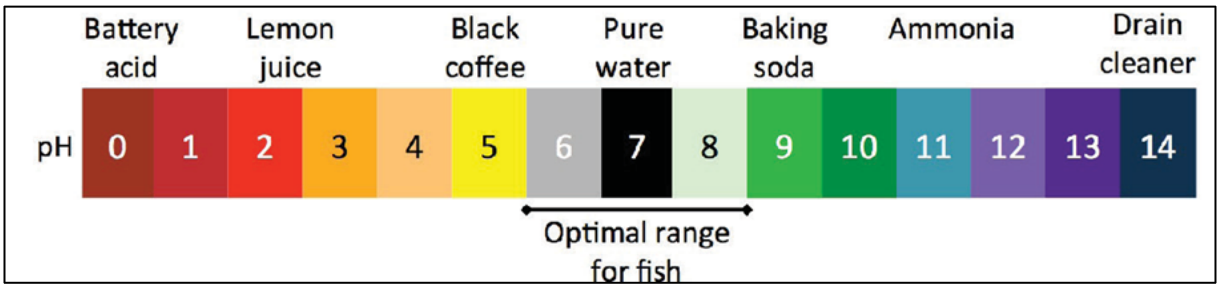


Figure 4.5.3. pH scale. Low and high pH waters are limiting for aquatic life; fish survive best at pH of 5–9.

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 (e.g., Davis 1975, Caraco and Cole 2002) (Table 4.5.3).

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

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 one-day acute criteria are applicable below critical low flow rates.

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: 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 be 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 cause 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: Change in Nephelometric Turbidity Units (NTUs)

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. In Wyoming, turbidity standards are in reference to changes caused by human activities and compared to baseline NTU observations. The turbidity measurement is also sometimes used as a surrogate for suspended sediment concentration.

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 from weeks to many years (e.g., Martıñez 1998, Tronstad 2015)—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 indicative of invertebrate community health 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* that 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). Expected percentile values were available for all macroinvertebrate metrics for Wyoming. Fort Laramie NHS belongs to the Southeast Plains bioregion, and we used the expected percentiles for that region to assign a condition value to the HBI based on the overall community tolerance (Hilsenhoff 1988, Hargett 2011). 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		HBI score
Warrants significant concern	🔴	6.81 – 10.00
Warrants moderate concern	🟡	5.91 – 6.80
Resource in good condition	🟢	0 – 5.90

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 Ephemeroptera, Plecoptera, and Trichoptera (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. Expected percentile values were available for all macroinvertebrate metrics for Wyoming. Fort Laramie NHS belongs to the Southeast Plains bioregion, and we used the expected percentiles for that region to assigned condition to EPT numbers (Hargett 2011). 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 (Hargett 2011).

Resource condition		EPT index
Warrants significant concern		< 7.5
Warrants moderate concern		7 – 14
Resource in good condition		> 14

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). We referred to reference conditions 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 the proportion of Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa (Hargett 2011).

Resource condition		Proportion EPT taxa
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 environmentally stressful conditions than uneven communities (Wittebolle et al. 2009).

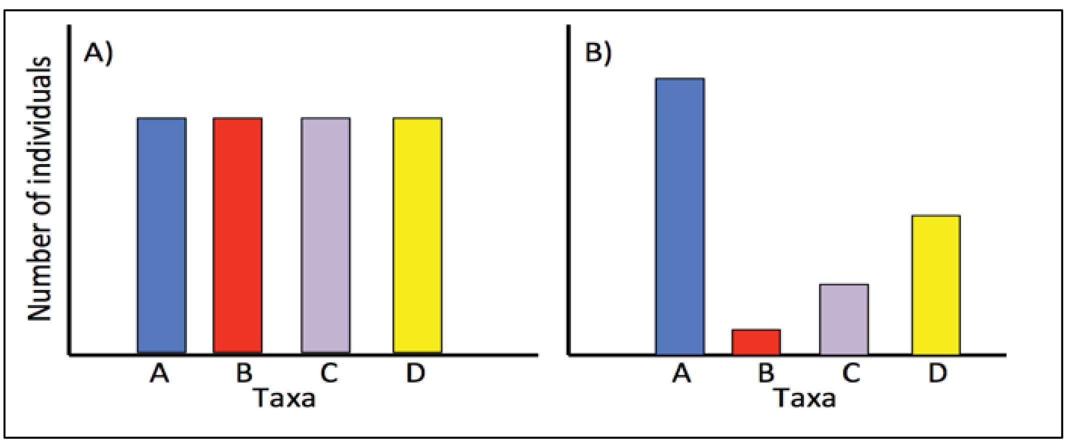


Figure 4.5.4. Illustration for describing taxa evenness. Taxa evenness is high if individuals are A) distributed similarly among taxa, and low if B) distributed unequally among taxa.

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).

Table 4.5.7. Water quality condition categories for taxa evenness.

Resource condition		Evenness score
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* (*E. coli*) is a well-known fecal coliform that has been associated with illness following food contamination. Fecal coliform standards and testing in Wyoming surface waters (Wyoming Statutes § 35-11 101–1803) 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 60-day period and must not exceed 126 colony-forming units (cfu)/100 milliliters (Wyoming Statutes § 35-11 101–1803). In single samples, the concentration of this bacterium is also regulated to standards reflective of designated recreation uses. If we did not have the requisite number of samples to apply a 60-day mean, we used single sample standards to evaluate *E. coli* condition. To identify which single sample standard was most appropriate, we assumed that surface waters in Fort Laramie NHS were unlikely to have high use swimming areas and, at most, would experience light use by swimmers; these assumptions were in line with a single sample maximum concentration of 410 colony-forming units/100 milliliters.

These standards do not apply to drinking water; fecal coliform must be absent from drinking water (0 colony-forming units/100 milliliters). We used a quartile approach to assign conditions (Table 4.5.8), such that concentrations up to the first quartile indicated *Good Condition*, the interquartile range indicated *Warrants Moderate Concern*, and concentrations above the third quartile indicated *Warrants Significant Concern*.

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

Resource condition		*E. coli* concentration (cfu/100 milliliters)
Warrants significant concern	🔴	308 ≤
Warrants moderate concern	🟡	205 – 308
Resource in good condition	🟢	≤ 205

Data Sources

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 Fort Laramie NHS. We conferred with experts to identify relevant monitoring data and reports for water quality at Fort Laramie NHS (L. Patterson, personal communication, 10 December 2015; L. Tronstad, personal communication, 20 January 2016). We identified several data sources within park boundaries: a summary report of water quality chemistry and biological indicators (Tronstad 2013) and a thesis on water quality (Rust 2006). Data collected by Tronstad (2013) 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 Rust (2006).

Sampling locations considered for this assessment included points on the Laramie River, North Platte River, and Deer Creek (Figure 4.5.5). Tronstad sampled three points on the Laramie River on September 8, 2011, for core indicators and invertebrate assemblage. Rust sampled twenty points on the Laramie River, ten points on the North Platte, and ten points in Deer Creek three times each between June, 2004, and May, 2005, for core indicators. She sampled each of these surface waters for fecal indicator bacterial levels; sampling was at one sampling location in each river visited two times between June, 2004–May, 2005; she also measured turbidity three times over this time period, sampling two points in each of the Laramie and North Platte Rivers and one point in Deer Creek.

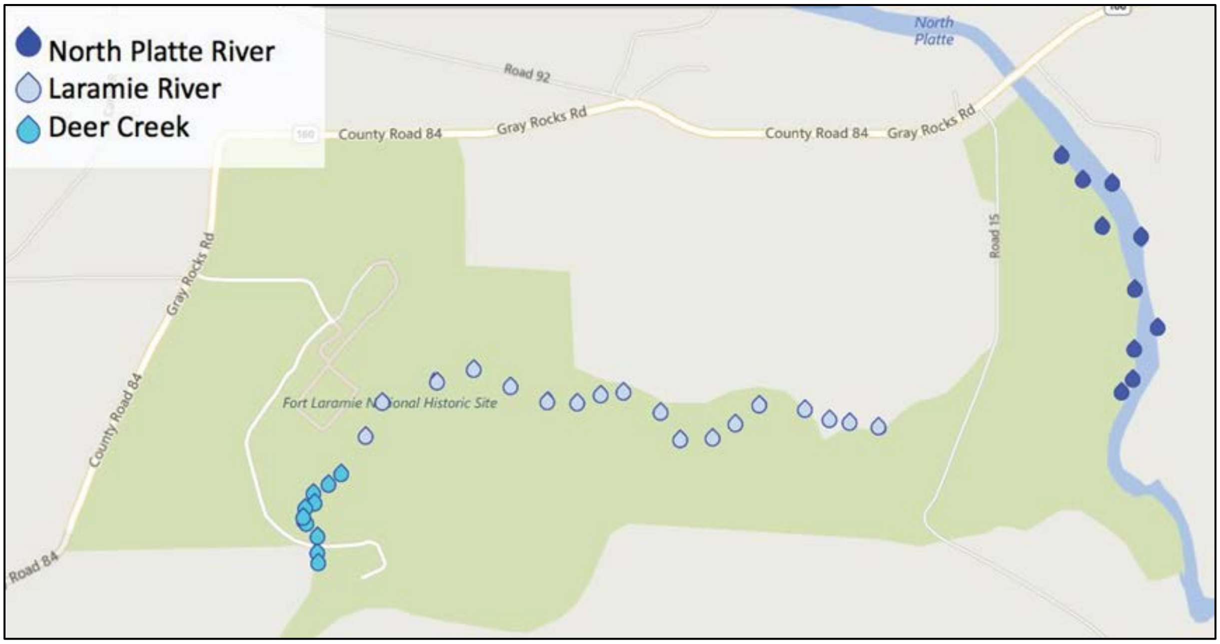


Figure 4.5.5. Water quality sampling locations along rivers and creeks at Fort Laramie NHS (modified from MyWATERS Mapper [EPA 2015]).

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 collected most recently and rigorously, for indicators for which there were multiple data sources. 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 Wyoming water quality 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 reliable 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 at least twice.

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).

Table 4.5.9. Summary of water quality indicators and measures.

<table>
<tr><th>Indicator</th><th>Measure</th><th>Condition</th><th>Confidence</th><th>Trend</th><th>Condition rationale</th></tr>
<tr><td>Acidity</td><td>pH</td><td>Resource in good condition</td><td>Medium</td><td>Not available</td><td>Acidity was within state standards during sampling period. Monitoring was not continuous for two years, so confidence was Medium and trend was Not Available.</td></tr>
<tr><td>Dissolved Oxygen (DO)</td><td>Milligrams/liter</td><td>Resource in good condition</td><td>Medium</td><td>Not available</td><td>DO was within state standards during sampling period. Monitoring was not continuous for two years, so confidence was Medium and trend was Not Available.</td></tr>
<tr><td>Temperature</td><td>°Celsius</td><td>Warrants moderate concern</td><td>Medium</td><td>Not available</td><td>Temperature was within state standards during sampling period. Monitoring was not continuous for two years, so confidence was Medium and trend was Not Available.</td></tr>
<tr><td>Turbidity</td><td>Nephelometric Turbidity Units (NTUs)</td><td>Not available</td><td>Low</td><td>Not available</td><td>Background data were unavailable, and monitoring was not continuous for two years. Confidence was Low and trend was Not Available.</td></tr>
<tr><td rowspan="2">Invertebrate assemblage</td><td>HBI</td><td>Warrants moderate concern</td><td>Medium</td><td>Not available</td><td rowspan="2">The average score of conditions indicated by all measures was 50, which warranted Moderate Concern. Monitoring was conducted at three sites in one stream for one year. Confidence was Medium and trend was Not Available.</td></tr>
<tr><td>• EPT index
• Proportion EPT
• Evenness</td><td>Warrants significant concern</td><td>Medium</td><td>Not available</td></tr>
</table>

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

Indicator	Measure	Condition	Confidence	Trend	Condition rationale
Fecal indicator bacteria	*Escherichia coli* (*E. coli*) count of colony forming units/100 milliliters	Resource in 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 core indicator data were collected in 2011 in the Laramie River and in 2005 in the North Platte River and Deer Creek.

Acidity

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

Condition

To assign a condition to acidity we used data summarized by Tronstad (2013) and Rust (2006). All three samples collected from the Laramie River in 2011 were within the acceptable range for pH (6.5–9.0) for Wyoming. Older observations were available for the North Platte River and Deer Creek; all available data were within the acceptable range for pH. These data placed acidity for Fort Laramie NHS in the *Resource in Good Condition* category.

Confidence

Acidity was calculated from pH data collected on-site at Fort Laramie NHS. The samples for the Laramie River were collected fairly recently, but not continuously, and were not repeated multiple times during the season. Data for the North Platte River and Deer Creek were collected over 10 years prior to this assessment and were not collected continuously. The confidence was *Medium*.

Trend

Acidity was calculated from pH data were not collected continuously, so data were insufficient to identify a trend. Trend was *Not Available*.

Dissolved Oxygen (DO)

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

Condition

To assign a condition to dissolved oxygen (DO) we used data summarized by Tronstad (2013, 2015) and Rust (2006). All three samples collected from the Laramie River in 2011 were within the acceptable range for DO (≥ 8 milligrams/liter) for Wyoming. Older observations were available for the North Platte River and Deer Creek; all available data were with the acceptable range for DO, given their stream classifications and the time of year that sampling occurred. These data placed DO for Fort Laramie NHS in the *Good Condition* category.

Confidence

Dissolved oxygen was calculated from data collected on site at Fort Laramie NHS. The samples for the Laramie River were collected fairly recently, but not continuously, and were not repeated multiple times during the season. Data for the North Platte River and Deer Creek were collected over 10 years prior to this assessment and were not collected continuously. The confidence was *Medium*.

Trend

Dissolved oxygen data were not collected continuously, so data were insufficient to identify a trend. Trend was *Not Available*.

Temperature

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

Condition

To assign a condition to temperature, we used data summarized by Tronstad (2013) and Rust (2006). All three samples collected from the Laramie River in 2011 were within the acceptable range for temperature (< 20 ºC) for 2AB cold fishery waters in Wyoming. Older observations were available for the North Platte River and Deer Creek; 67% of temperature observations in the North Platte River exceeded the allowed temperature value, but temperatures within Deer Creek were within the acceptable range for a class 2C stream. We took the average of these data conditions to assign an indicator score; we did not weight the score because, though Rust (2006) sampled more points in 2004–2005, the data collected by Tronstad (2013) were more recent. The score of 50 placed water temperature for Fort Laramie NHS in the *Warrants Moderate Concern* category.

Confidence

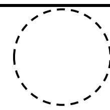
Temperature data were collected on-site at Fort Laramie NHS. The samples for the Laramie River were collected fairly recently, but not continuously, and were not repeated multiple times during the season. Data for the North Platte River and Deer Creek were collected over 10 years prior to this assessment and were not collected continuously. The confidence was *Medium*.

Trend

Temperature data were not collected continuously, so data were insufficient to identify a trend. Trend was *Not Available*.

<u>Turbidity</u>

Turbidity data were most recently collected in 2005 by Rust (2006); she sampled turbidity three times at two points in each of the Laramie and North Platte Rivers, and at one point in Deer Creek.



Condition: Not Available
Confidence: Low
Trend: Not Available

Condition

To assign a condition to turbidity, we would have needed baseline data for each stream to reference against the seasons during which Rust (2006) took measurements. While turbidity appeared to be low in all rivers or streams, we were unable to compare to reference conditions and conclude that changes in turbidity were ≤ 10 NTU in the large rivers. The maximum turbidity observed in Deer Creek was 3 NTU and, therefore, could not have exceeded a magnitude in change of > 10 NTU. Condition was *Not Available*.

Confidence

Turbidity data were collected on site at Fort Laramie NHS, but samples were not collected continuously, were collected > 10 years prior to this assessment, and reference data did not exist for any of the surface waters. The confidence was *Low*.

Trend

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

<u>Invertebrate Assemblage</u>

The most recent invertebrate data were collected in 2011 in the Laramie River and in 2005 in the North Platte River and Deer Creek.

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

Condition

We used data collected by Tronstad (2013) 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):** The average value of HBI was 4.8. This value indicated an HBI condition of *Warrants Moderate Concern* at Fort Laramie NHS.
- **EPT Index:** The average value of EPT index was 11.3. This value indicated an EPT condition of *Warrants Significant Concern* at Fort Laramie NHS.
- **Proportion EPT:** The average value for proportion EPT of total invertebrate samples was 0.53. This value indicated a proportion EPT condition of *Warrants Moderate Concern* at Fort Laramie NHS.
- **Evenness:** The average value for evenness was 0.59. This value indicated an evenness condition of *Warrants Moderate Concern* at Fort Laramie NHS.

The average of conditions indicated by all measures was 50, which placed the condition of macroinvertebrate assemblage at Fort Laramie NHS in the category, *Warrants Moderate Concern*.

Confidence

Macroinvertebrate data were collected on site at Fort Laramie NHS at three locations once in 2011. Macroinvertebrate condition reflects long term environmental conditions, unlike the snapshot nature of chemical sampling, so infrequent sampling schedule can be sufficient to indicate water quality. At Fort Laramie NHS, however, samples had not been collected from the North Platte River or Deer Creek in the 10 years prior to this assessment. Confidence was *Medium*.

Trend

Data were insufficient to assign a trend. Trend was *Not Available*.

Fecal Indicator Bacteria (Fecal coliform)

Fecal indicator bacterial levels were most recently sampled by Rust (2006) from one sampling location in each river visited twice between June, 2004, and May, 2005.

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). Samples for Laramie River and North Platte were well below the maximum allowed coliform count (410 colony forming units/100 milliliters). One coliform count sample in Deer Creek (250 colony forming units/100 milliliters) fell in the interquartile range that we calculated for single samples. The average of these conditions, however, placed the fecal bacteria indicator for Fort Laramie NHS in the *Resource in Good Condition* category.

Confidence

Fecal indicator bacteria condition was calculated from data collected on site at Fort Laramie NHS, but data were collected for only one year over 10 years prior to this assessment. 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 only one year, so data were insufficient to identify a trend. Trend was *Not Available*.

Water Quality Overall Condition

Table 4.5.10. Water quality overall condition.

Indicators	Measures	Condition
Acidity	• pH	
Dissolved oxygen	• mg/L	
Temperature	• °C	
Turbidity	• NTUs	

Table 4.5.10 (continued). Water quality overall condition.

Indicators	Measures	Condition
Invertebrate assemblage	• HBI • EPT index • % EPT • Evenness	
Fecal indicator bacteria	• *E. coli* concentration	
Overall condition for all indicators and measures		

Condition

Overall water quality condition was determined by the average of the indicator conditions, excluding turbidity. We summarized the condition, confidence, and trend for each indicator, and assigned condition points. The total score for overall water quality condition was 80 points, which placed water quality at Fort Laramie NHS in the *Resource in Good Condition* category.

Confidence

Confidence was Low for Turbidity and *Medium* for all other indicators. The score for overall confidence was 42 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*.

4.5.5. Stressors

Water quality at Fort Laramie NHS was generally high. Upstream infrastructure and activities most likely to affect water quality in the Laramie River are grazing, hay production, and flow alteration from Grayrocks Reservoir and Wheatland Reservoir (Tronstad 2013), but none of these factors is new and the large rivers are in good condition. Changes to land use or land management practices could, however, have consequences in the future. Deer Creek, the one surface water in Fort Laramie NHS with high fecal coliform levels, has been accessible by livestock that can graze the banks and enter the stream (Rust 2006). Livestock are present on the Laramie River from immediately above the historic site all the way up to the upper reaches of the system in Albany County, Wyoming, and Larimer County, Colorado. Deer Creek runs through a corral as it enters the boundary of Fort Laramie NHS, perhaps explaining a high fecal coliform level. Deer Creek's entire watershed is exposed to livestock grazing (M. Evans, personal communication, 7 July 2016).

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 Fort Laramie NHS were limited to samples collected once in one river in the last 10 years. Continuous sampling is required to determine trend in water quality. Continuous sampling within the park for at least two years would improve assessment efforts to understand the water quality condition at Fort Laramie NHS. 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 Fort Laramie NHS will depend on the specific objectives of NPS management.

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4.6. Geology

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.

Laramie River at Fort Laramie NHS (Photo: Lusha Tronstad 2013).

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 2009).

Geologic 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. Within Fort Laramie NHS, seasonal flooding is the main geologic hazard of concern (Graham 2009). While some seasonal flooding is a natural process, it can have a negative impact on park resources such as roads and bridges and as such is a major park management concern. This assessment is limited to the condition of the natural resources at Fort Laramie NHS, but these assessments should be considered in the context of the other founding goals of the park.

The Great Plains region has not been seismically active for millions of years, and earthquakes are uncommon in the area. Small earthquakes have occurred nearby, however, in the northern Laramie Range in Wyoming approximately 71 kilometers (~44 miles) northwest of Fort Laramie NHS and also near Guernsey, WY, 18 kilometers (~11 miles) to the northwest (Case 2002). Historic records show that a significant earthquake in 1882 was felt at Fort Laramie, and in 1984 an earthquake centered in northern Albany County was felt in the town of Fort Laramie and cracked the wall of the school building there (Graham 2009).

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 and immediately surrounding Fort Laramie National Historic Site, the oldest rocks exposed within the boundaries of Fort Laramie NHS are Quaternary river deposits of Pleistocene age (2.58 million to 11,700 years ago) and younger (Graham 2009).

The Tertiary strata that crop out in the region around Fort Laramie are an important sequence of rocks that 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 (Prothero and Emry 2004).

Because differential erosion across the region has removed some parts of these Tertiary strata and left others in place, outcrops across the area preserve different segments of the EOT (Prothero and Emry 2004). In the area surrounding Fort Laramie NHS, outcrops of the middle Miocene Arikaree Formation record the environment and the fauna following this climactic transition. The Arikaree Formation is rich in vertebrate fossils in nearby areas, yielding fossils of oreodonts as well as Daemonelix, the large corkscrew-shaped burrow of the early beaver Paleocastor (Graham 2009). Although these strata do not crop out within Fort Laramie, they are found immediately to the south of the boundary, and any expansion in that direction could potentially impact these rocks and the fossils they may contain.

The only sedimentary deposits within Fort Laramie NHS are the unconsolidated river muds, sands and gravels of the Laramie and North Platte Rivers. These deposits range from Pleistocene to recent in age. No fossils are known from these deposits, although fossils of ice-age mammals such as mammoths and bison are known from similar deposits in the region (Pinsof 1985).

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; 43 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 Fort Laramie NHS depends on the condition of a single indicator: sediment transport.

Indicator: Sediment Transport

Fort Laramie NHS is located along a bend of the Laramie River where it flows into the larger North Platte River. Both of these rivers are meandering, and their active channels naturally migrate laterally across the floodplain, transporting sediment by eroding previous deposits and laying down new ones (Figure 4.6.1).

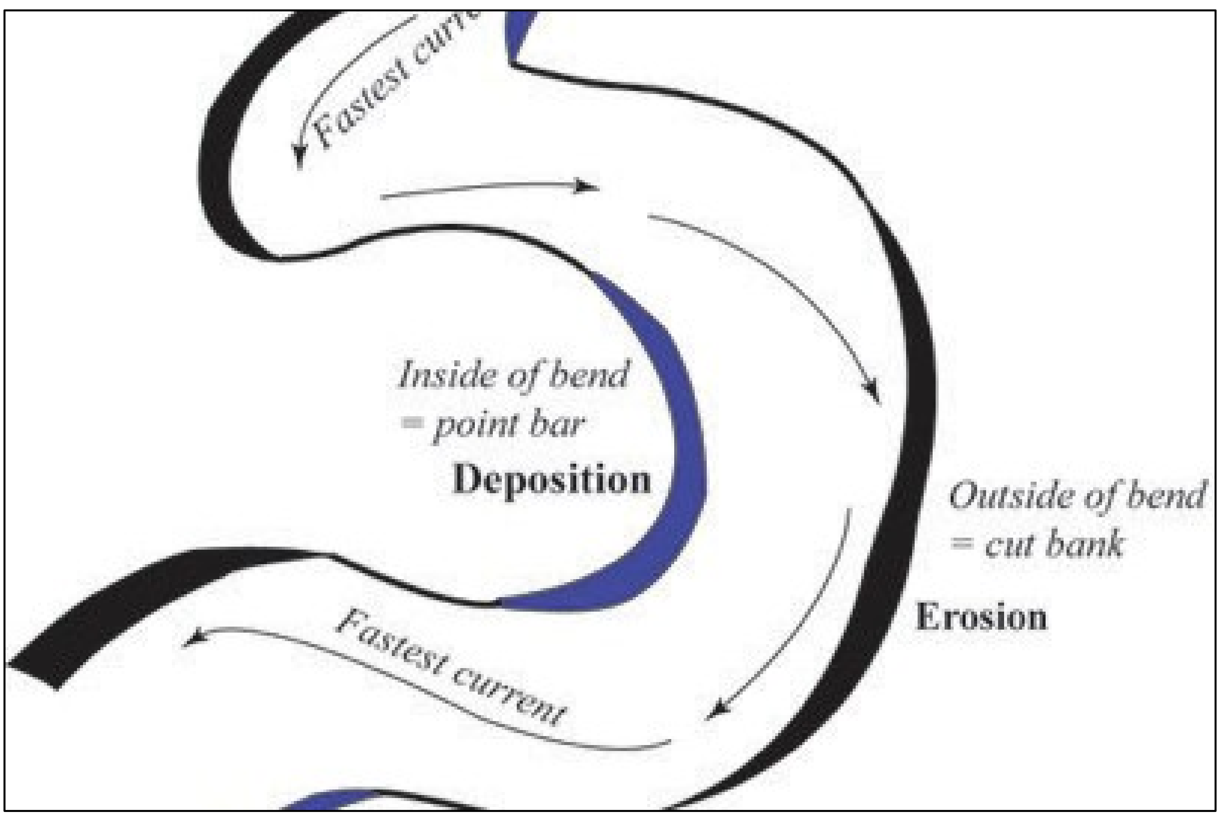


Figure 4.6.1. Generalized pattern of sediment transport in a meandering stream.

Under natural conditions, meandering streams erode along the concave (outside) parts of the bends, and deposit along the concave (inside) parts. Bank undercutting can occur during flood events, and subsequent bank failure and collapse are possible after flood waters subside as a result of changing pore-water levels in the soils and clays in the banks (Leeder 1982). These processes result in lateral migration of river channels, and Google Earth aerial images of Fort Laramie NHS clearly show meander scars as well as patterns of vegetation indicating previous positions of the river channel (Figure 4.6.2). Due to the unconsolidated nature of modern river deposits, significant erosion and deposition do not require extraordinary floods but can also occur with lower-energy seasonal stream discharges.

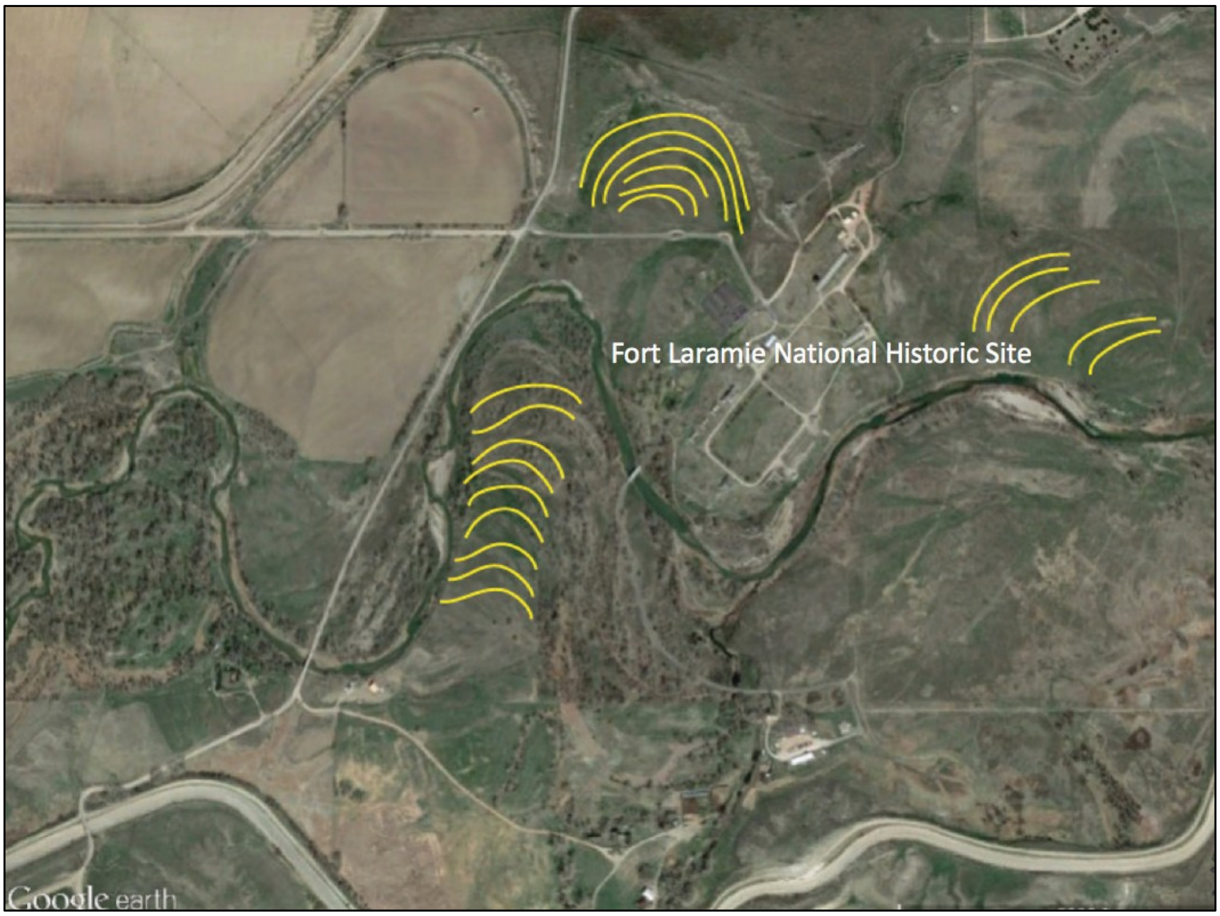


Figure 4.6.2. Google Earth view of Fort Laramie NHS, 4/23/2014. Yellow marks show some of the meander scars from the migration of the Laramie River channel.

Measure of Sediment Transport: Flooding Consistency with Respect to Historical Record

We measured sediment transport by using flooding events as a proxy for erosion and deposition of sediment. Floodwaters are a major cause of both erosion and deposition along rivers, and the frequency of flooding within Fort Laramie NHS has been documented in historical accounts. We assessed condition of sediment transport using a historical comparison with similar events. Although there are currently no quantitative data on the specific amounts of erosion and deposition occurring along the riverbanks within Fort Laramie NHS, we used qualitative data to assess erosion and deposition rates. These observations allowed us to make a coarse assessment of resource condition, using flooding as a proxy for erosion and deposition. The intensity of flooding events can be directly tied to the potential for erosion and deposition along a river, as the increased volume and velocity of water during flood events can cause increased erosion and deposition (Leeder 1982).

Flooding events along meandering streams are normal and natural, and can demonstrate that the river—and, by proxy, sediment transport—is behaving in a manner consistent with natural conditions. Historical observations of these patterns allowed us to make qualitative estimates of the amount of erosion and deposition along the riverbanks; using these observations we identified if recent river patterns were within the bounds of natural conditions or whether river behavior has been impacted by human activities, such as damming. For our purposes here, significant flooding events were those that were documented in park reports and/or media accounts. Moderate flooding events were those that occurred each spring but did not have enough impact to be recorded. Both types of flooding are within expected natural conditions for meandering streams such as the Laramie and North Platte Rivers (Leeder 1982).

If flooding events were significantly outside the range of natural conditions, we gave the highest level of concern *Warrants Significant Concern*. If flooding events were moderately outside the range of natural conditions, we assigned the condition *Warrants Moderate Concern*, meaning that the resource was not completely within the bounds of expected natural conditions. If recent flooding events were within the bounds of expected natural conditions, we assigned the condition *Resource in Good Condition* (Table 4.6.1).

Table 4.6.1. Geologic resource condition categories for flooding consistency with respect to historical record.

Resource in good condition		Flood consistency with natural conditions
Resource in good condition		Flooding events significantly outside the historic range of natural conditions
Resource in good condition		Flooding events moderately outside the historic range of natural conditions
Resource in good condition		Flooding events within the historic range of natural conditions

<u>Measure of Sediment Transport: Observed Changes in Active Channel Position</u>

As discussed above, the shape of a meandering stream's channel is the result of the erosion and deposition of the sediment transported by the river. We thus looked at the past and present positions of the Laramie River channel to understand the natural conditions for that river. We used aerial images from Google Earth to observe the long-term behavior of the river as seen in meander scars (Figure 4.6.1), and we looked at the shorter-term behavior of the river using aerial photos taken by the USGS in 1947. Observations of these patterns of channel movement allowed us to make qualitative estimates of the amount of sediment transported by the river and to determine if the river is behaving within the bounds of expected natural conditions, or whether its behavior has been impacted by human activities such as damming.

Meandering streams can be expected to move their channels under natural conditions. If the river channel position was significantly outside historic range of natural conditions, we gave the highest level of concern, *Warrants Significant Concern*.

If changes in channel position occurred and were mostly as expected under natural conditions, we assigned the condition *Warrants Moderate Concern*. If changes in channel position occurred and those changes were completely as expected under natural conditions, we assigned the condition *Resource in Good Condition* (Table 4.6.2).

Table 4.6.2. Geologic resource condition categories for observed changes in active channel position.

Resource in good condition		Channel position consistency with natural conditions
Resource in good condition		Changes in channel position significantly outside historic range of natural conditions
Resource in good condition		Observed changes in channel position moderately outside historic range of natural conditions
Resource in good condition		Changes in channel position within historic range of natural conditions

Data Sources

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

There were no quantitative data available on sediment transport at Fort Laramie NHS. Instead, we referred to qualitative information from past significant impacts to the resource, aerial views of the river channel placement, and expert opinion to assess geologic condition.

Quantifying Geological Resources 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 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 Fort Laramie NHS this time period is 79 years (Graham 2009). 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 Geological Resources 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 rational
Sediment transport	Flooding with respect to historical record	Resource in good condition	Medium	Not available	Erosion and deposition caused by flooding events along the riverbanks has occurred in the past, and continues to occur. This assessment places this measure in the *Resource in Good Condition* category, as the resource is within the bounds of expected natural conditions. There were no on-site or nearby monitoring data, but qualitative data was available; confidence was *Medium* and trend was *Not Available*.
	Observed changes in active channel position	Warrants Moderate Concern	Medium	Not available	Aerial views of the Laramie River show that the river's active channel has migrated across the entire floodplain in the past, as expected for this type of river. Aerial photos also show that one part the channel has migrated in a direction not consistent with expected natural conditions. This assessment places this measure in the *Warrants Moderate Concern* category, as the resource is behaving mostly within the bounds of expected natural conditions with some deviation. There were no on-site or nearby monitoring data, but qualitative data was available; confidence was *Medium* and trend was *Not Available*.

4.6.4. Geological Conditions, Confidence, and Trends

<u>Sediment Transport</u>

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

Condition

Sediment transport is not currently and has not historically been measured within Fort Laramie NHS. Instead, we assigned conditions based on qualitative information from descriptions of past impacts to the geologic resource using flooding as a proxy for sediment transport, as well as visual estimates of the movement of the active river channel from Google Earth and USGS aerial images.

Accounts by park personnel indicated that flooding (and, by proxy, erosion and deposition) has occurred in Fort Laramie NHS (Graham 2009, Mattes 1980). Although we were unable to quantify the number of discrete flood events over the history of Fort Laramie, significant flooding has historically been a regular occurrence (Mattes 1980). In a written account of the history of Fort Laramie from 1834–1977, flooding was described as a major issue for the soldiers and emigrants passing through the area:

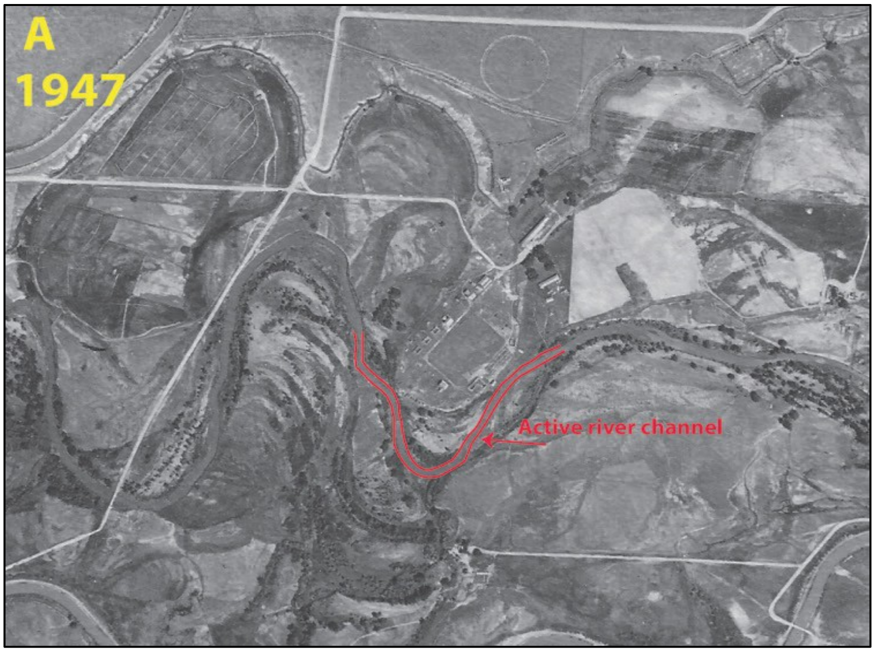
> *No account of emigrant facilities at Fort Laramie would be complete without reference to the two main trail approaches and river crossings…In June the Laramie was apt to be in flood, causing wagons to capsize and emigrants to be swept to their deaths. There is evidence of a flat-boat shuttle across the Laramie on occasion, but most crossings were "cold turkey" until 1852 when a crude toll bridge was erected. However, a solid flood-proof bridge did not materialize until 1859* (Mattes 1980, p. 22).

Although details of specific flooding events are not discussed in this account, reference is made to a flood in 1973 being called the "worst on record." The author is skeptical of this claim, stating that, "although hydrographic records of Army days are lacking, there is ample evidence of severe floods during the 1880s that took out several Fort buildings" (Mattes 1980, p. 190). More recently, in May of 2015 the Laramie River reached historic high-water levels due to heavy spring rains upstream (National Parks Traveler 2015, Boyer 2015).

The descriptions of flooding in this historical account, along with the accounts of the more recent flood, show that significant floods are a regular occurrence on the Laramie River within Fort Laramie NHS (Mattes 1980, National Parks Traveler staff 2015, Boyer 2015). Similar floods have occurred in the past and are likely to occur in the future, and thus sediment erosion and deposition along riverbanks is likely to occur. Based on our classification of significant flooding as flooding that had enough impact to be recorded, we assigned a condition of *Resource in Good Condition* to the measure of erosion and deposition along riverbanks supporting the conclusion that the resource is within the bounds of expected natural conditions and awarded 100 points to the measure.

In our analysis of aerial images, we observed that the position of the active channel of the Laramie River has changed substantially over time, as would be expected for a river of this type. Arc-shaped meander scars are visible in aerial images, indicating that the active channel of the Laramie River has migrated over time as a result of sediment transport (Figure 4.6.2). The river has inhabited its entire floodplain as demonstrated by the pattern of the meander scars, with the meanders moving both forward and backward at various times.

Inspection of an aerial photograph taken by the USGS in 1947 demonstrates that the position of one part of the river channel—directly to the south of the historic buildings—has changed in a way that may be outside the bounds of expected natural conditions. The river channel in this area has moved closer to the buildings by approximately 250 feet compared to the position on the 1947 aerial photograph (Figure 4.6.3). This type of channel behavior can be a natural occurrence, as during floods meandering streams can breach the narrow necks that form between meanders when the sinuosity becomes extreme (Leeder 1982).



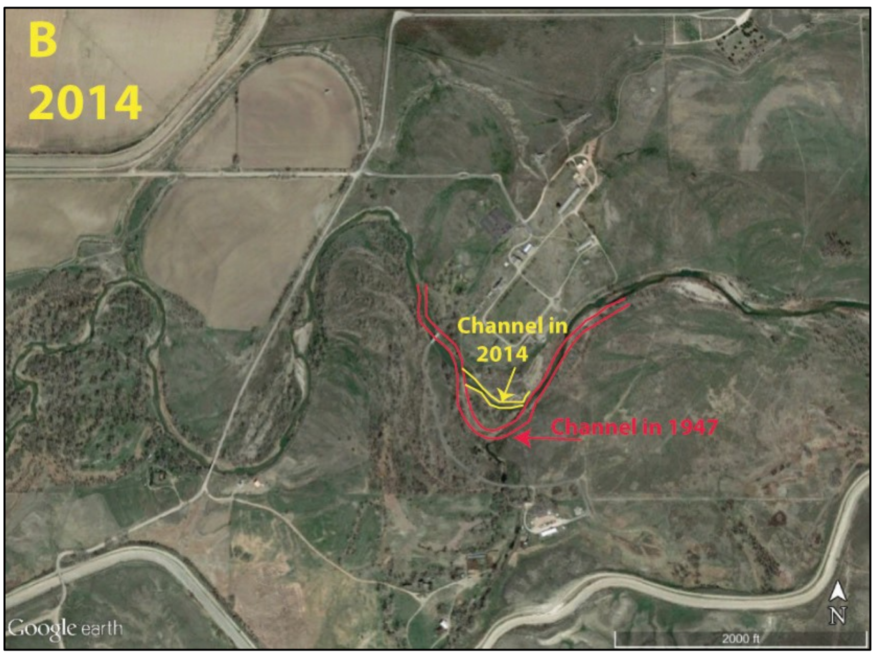


Figure 4.6.3. Aerial photos showing relative position of active channel of the Laramie River. A) 1947 USGS photo, with active river channel outlined in red. B) 2014 Google Earth image, with 1947 channel in red and current active channel in yellow.

In this case, however, the sinuosity of the river at this point does not seem extreme enough for this type of breaching to occur. Instead, based on the generally recognized pattern of meandering river erosion and deposition (Figure 4.6.1), we would expect the river to continue to move away from the historic buildings in that area. This possible difference between expected and observed movement could be a result of several variables, including changes in outflow from Grayrocks Reservoir.

Based on these observations of changes in channel position occurring and those changes being mostly within expected parameters, we gave the medium level of concern, *Warrants Moderate Concern*, meaning that the resource is behaving mostly within the bounds of expected natural conditions with some deviation, and we gave the measure 50 points.

The average of both measures determined the condition category of the indicator; as the average score of both measures was 75, this supports a condition of *Resource in Good Condition* for the indicator of sediment transport.

Confidence

There were no available quantitative data on sediment transport, but observations of previous flood events were available, as were aerial images that we analyzed. We were able to estimate previous river channel position using expert opinion, thus achieving a *Medium* confidence in this indicator.

Trend

In the absence of quantitative data, we were unable to assign a trend to sediment transport. Trend was *Not Available*. There were, however, some long-term qualitative data available from historic accounts of flooding at Fort Laramie as well as from the sedimentary record as seen in aerial photos to guess that trend may not have changed much for the indicator of sediment transport.

Geological Resource Overall Condition

Table 4.6.4. Geological resources overall condition.

Indicators	Measures	Condition
Sediment transport	• Natural range of variation: flooding consistency • Natural range of variation: channel position	

Condition

The overall geologic resources condition was determined by the condition of the single indicator, sediment transport (Table 4.6.4). Sediment transport was given a condition of *Resource in Good Condition*, which placed the overall geologic resource condition for Fort Laramie NHS in the category *Resource in Good Condition*.

Confidence

Confidence was *Medium* for the single indicator of sediment transport, so overall confidence was *Medium* for geologic resources.

Trend

Trend data were *Not Available* for the single indicator of sediment transport, so overall trend for geologic resources was *Not Available*.

4.6.5. Stressors

We identified one stressor to the geologic resources of Fort Laramie NHS: the potential effects of climate change on seasonal flooding of the Laramie River. Climate change is an incredibly complex issue, and it has the potential to substantially change river flood hazards (Arnell and Gosling 2016). There is a considerable amount of uncertainty in the magnitude of this impact depending on which regional climate change scenario is used, however, and currently it is difficult to predict how a specific river may respond to future variation in climate. For the Laramie River, climate change may increase flooding frequency and/or magnitude, or it may decrease frequency and magnitude (Arnell and Gosling 2016).

4.6.6. Data Gaps

As discussed above, there is currently no direct measurement of the rates of sediment transport along the rivers in Fort Laramie NHS. There are many common methods to assess these rates (e.g., Lawler 1993), and most of these are relatively inexpensive. These data could greatly help in determining overall rates of sediment transport, in assessing the impact of yearly flood events, and in determining the effects of sporadic discharges from Grayrocks Reservoir upstream from Fort Laramie on the Laramie River.

Measurements can be taken at specific locations along cut banks and point bars to quantify the amount of erosion and deposition occurring each year. Methods commonly used to measure riverbank erosion and deposition on short-term scales (months to ~10 years) include the use of erosion pins, photogrammetry, and planimetric surveys. For longer timescales (tens to thousands of years), sedimentological data and evidence from botanical surveys can be used, as well as historic accounts including early maps, surveyors' notes, and aerial photos (Lawler 1993).

As part of an archaeological excavation from 1994–1996 of the Fort Laramie Quartermaster Dump area, a grid system was established to provide a permanent reference for future excavations. This grid was intended also to provide a reference base for future monitoring of riverbank erosion, and two concrete markers were placed away from the riverbank but still within the grid to serve as reference points for erosion monitoring (Walker 1998). While it is unclear if these markers were utilized as intended, they may still be useful for future studies of riverbank erosion.

The National Weather Service currently monitors the water levels near Fort Laramie on the Laramie River (NWS 2016). Although this monitoring does not directly measure the amount of sediment transport occurring, these regular water level measurements could be combined with the simple measures described above to provide useful data on this indicator. In addition, measurement of the actual distance the river channel has moved since the area was first settled could possibly be obtained through use of the maps, notes, and diaries of the early explorers and surveyors. These data could then be used to provide park managers with a better prediction of the future movements of the river channel. Especially in light of the importance of preserving the historic structures along the rivers in Fort Laramie NHS, having these data would help park managers to plan both short-and longer-term protections for these cultural resources. The USGS began monitoring water discharge on the Laramie River near Fort Laramie NHS in 2007 and, if monitoring continues in the future, this data set will be valuable to identifying long-term trends in flow rates in the river.

Quantitative data on the amount of movement of the river channel would be useful for fine-tuning predictions of future migration of the river channel. Using historic accounts of the exploration and settlement of Fort Laramie and the surrounding area along with current observations, it may be possible to determine specifically how far the river channel has moved in the past 180 years. This information could then be used to estimate how much the river channel tends to migrate each decade and which directions it may move in the future.

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4.7. 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 Fort Laramie National Historic Site*. The authors of the Fort Laramie 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 added by the NRCA authors is limited to the descriptions of indicators and measures in the methods section, the brief description of methods in the Quantifying Overall Vegetation Condition, Confidence and Trend section, and section 4.7.5, Vegetation Overall Condition. Figure and table numbers were also updated to match the format of the NRCA.

4.7.1. Background and Importance

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.

Fort Laramie National Historic Site (FOLA), established in 1938 to protect and preserve the well-known military post, covers 833 acres on the boundary of the northern mixed-grass and short-grass prairie region (Lauenroth et al. 1999). The park is a mosaic of disturbed old-fields, riparian forests, and native prairie and is host to 376 plant species (Heidel 2004). The Northern Great Plains Inventory & Monitoring Program (NGPN) began vegetation monitoring at FOLA in 2011 (Ashton et al. 2012). A total of 30 plots were established in FOLA (Figure 4.7.1); 15 plots were randomly distributed throughout the park to better study herbaceous plant communities, 15 plots were established in the riparian forest to assess forest condition, and 5 plots were used to study both forest condition and herbaceous plant communities.

Using 5 years of plant community monitoring data in FOLA, we explore the following questions:

- What is the current status of plant community composition and structure of FOLA grasslands (species richness, cover, and diversity) and how has this changed from 2011-2015?

- How do trends in grassland condition correlate with climate?
- What, if any, rare plants were found in FOLA long-term monitoring plots?
- What is the composition and structure of riparian forests at FOLA?

Figure 4.7.1. Map of Fort Laramie NHS and plant community monitoring plots (Ashton and Davis 2016). The blue area represents the riparian area of the park. There are three different types of monitoring plots: upland herbaceous (red), riparian woody plots (yellow).

4.7.2. Methods

The NGPN Plant Community Composition and Structure Monitoring Protocol (Symstad et al. 2012b, a) was used to monitor long-term vegetation plots at FOLA. Below, we briefly describe the general approach but for those interested in more detail please see Symstad et al. (2012a), available at http://science.nature.nps.gov/im/units/ngpn/monitor/plants.cfm.

<u>Sample Design</u>

We implemented a survey to monitor plant community structure and composition in FOLA using a spatially balanced probability design (Generalized Random Tessellation Stratified [GRTS]; Stevens and Olsen 2003, 2004). Using a GRTS design, we selected 15 randomly located sites within FOLA (Figure 4.7.1). We visited 6 sites every year, and after five years (2015) we had visited all 15 sites twice (or attempted to). Visits were made during the first week of June.

In 2014, we used the GRTS design to select 20 plots within riparian forest communities at FOLA. The riparian corridor was delineated in the field and defined as everything below the highest river terrace (Figure 4.7.1). It comprised approximately 29% of the park. Four of the previously selected plots fell within the riparian forest, so these were used (dual plots) and 16 new plots were selected (Figure 4.7.1).

<u>Plot Layout and Sampling</u>

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 4.7.2). Data on ground cover, herb-layer height ≤ 2 meter, and plant cover were collected on two 50 meter transects (the long sides of the plot) using a point-intercept method (Figure 4.7.3). Species richness data from the point-intercept method were supplemented 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 4.7.2).

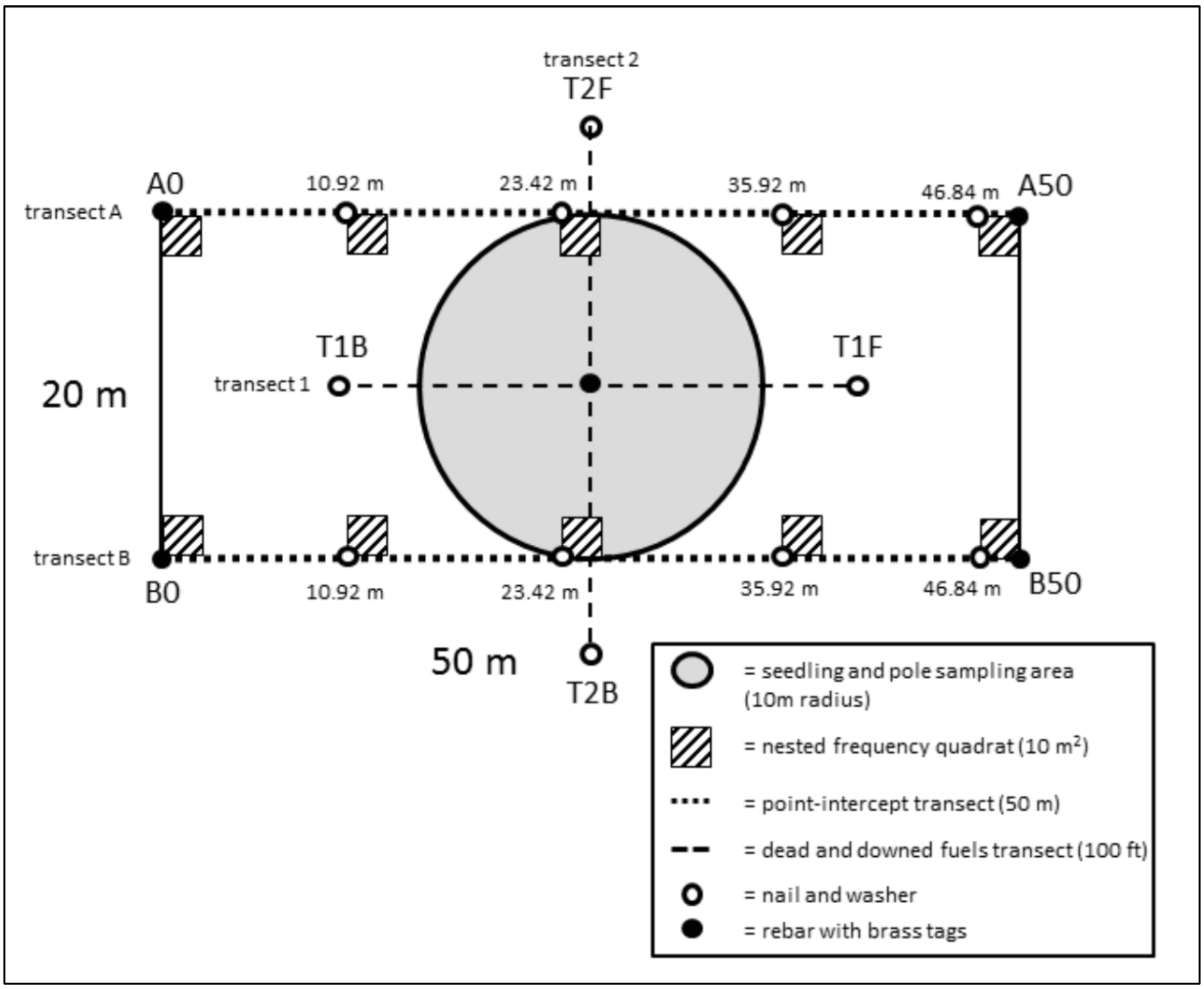

Figure 4.7.2. Long-term monitoring plot layout used for sampling vegetation in Fort Laramie NHS (Ashton and Davis 2016).

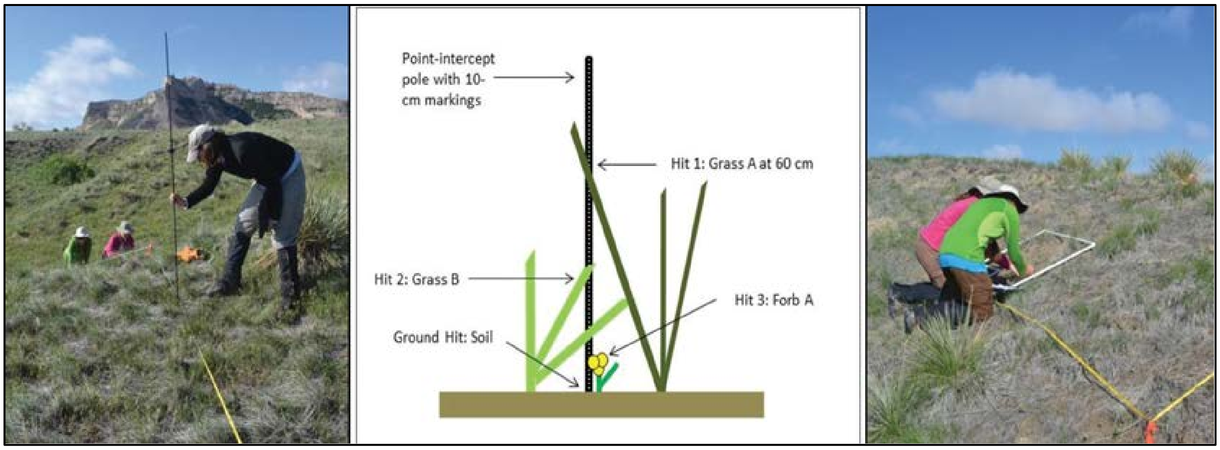

Figure 4.7.3. Images of vegetation inventorying and monitoring methods at Scotts Bluff National Monument. The Northern Great Plains Inventory & Monitoring vegetation crew used point-intercept (left and center panel) and quadrats (right panel) to document plant diversity and abundance. These photographs were taken at Scotts Bluff National Monument, but the same methods were used at Fort Laramie NHS.

When woody species were also present (e.g., the plots in the riparian area), tree regeneration and tall shrub density data were collected within a 10 meter radius subplot centered in the larger 50 meter x 20 meter plot (Figure 4.7.2). Trees with diameter at breast height (DBH) > 15 centimeter, located within the entire 0.1 hectare plot, were mapped and tagged. For each tree, the species, DBH, status, and condition (e.g., leaf-discoloration, insect-damaged, etc.) were recorded.

To increase the number of forested plots and our understanding of riparian forest condition, NGPN completed a survey in the last week of August 2014 using a set of 20 forested sites. In this case, seedlings and poles were measured as described above, but larger trees (DBH > 15 centimeters) were not tagged and only measured within the 10 meter radius subplot. Dead and downed woody fuel load data were collected at these forested plots on two perpendicular, 100 feet (30.49 meters) transects with midpoints at the center of the plot (Figure 4.7.2), following Brown's Line methods (Brown 1974, Brown et al. 1982). The fuels data were not reported because grasses dominated the fuel layer. This forest survey will be repeated every 5 years (e.g. 2019, 2024, etc.).

At all plots, we surveyed the area for common disturbances and target species of interest to the park. Common disturbances included such things as flooding, rodent mounds, and animal trails. 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 park and cause significant ecological impacts (Table 4.7.1). These species were chosen in collaboration with the Midwest Invasive Plant Network, the Exotic Plant Management Team, park 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 4.7.1. Exotic species surveyed for at Fort Laramie NHS as part of the early detection and rapid response program within the Northern Great Plains Network (Ashton and David 2016).

Scientific 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 solstitialis	Yellow star thistle	Upland
Hieracium auranthiacum; 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 duba	African wiregrass	Upland

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 4.7.2 for a detailed definition of each conservation status rank.

Table 4.7.2. Definitions of state and global species conservation status ranks.* Adapted from NatureServe status assessment table (http://www.natureserve.org/conservatio-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 more than one rank

* S = state ranks, G = global ranks.

Plant life forms (e.g., subshrub, forb) were based on definitions for each species from the USDA Plants Database (USDA-NRCS 2015). The conservation status ranks of plant species in FOLA were based on the species list maintained by the Wyoming Natural Diversity Database, and for the purpose of this report, a species was considered rare if it was S1, S2, or S3. See Table 4.7.2 for a detailed description of conservation ranks.

We measured diversity at the plots in 2 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. 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. 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 Old Fort Laramie, WY weather station were downloaded from NOAA's online database (NOAA 2015).

Reporting on Natural Resource Condition

Results were summarized in a Natural Resource Condition Table based on the templates from the State of the Park report series (http://www.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 that can describe the condition of vegetation in the Northern Great Plains and the status of exotic plant invasions. The measures include: native species richness, evenness, relative cover of exotic species, and annual brome cover.

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 Fort Laramie NHS was first established. Much of the prairie has 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). Understanding the composition and structure of upland species within park will help with efforts to protect the remnants of native prairie that are 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: Native 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 (Figure 4.7.4). 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 environmentally stressful conditions than uneven communities (Wittebolle et al. 2009).

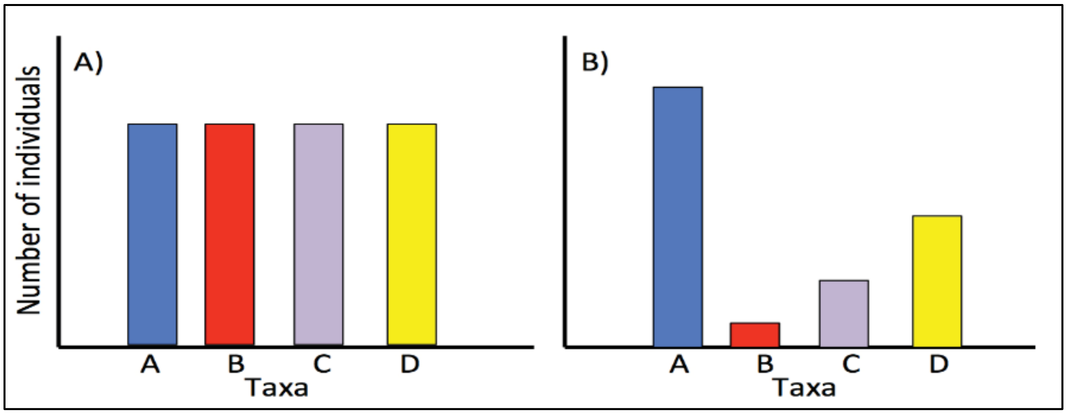

Figure 4.7.4. Illustration for describing taxa evenness. Taxa evenness is high if individuals are A) distributed similarly among taxa, and low if B) distributed unequally among taxa.

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 Fort Laramie NHS is important for protecting the native prairie within in the park.

Measure of Exotic Plant Early Detection and Management: 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 Exotic Plant Early Detection and Management: Annual Brome Cover

There is evidence from other regions that annual bromes can affect persistence of native species (D’Antonio and Vitousek 2003). In the 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 4.7.5).

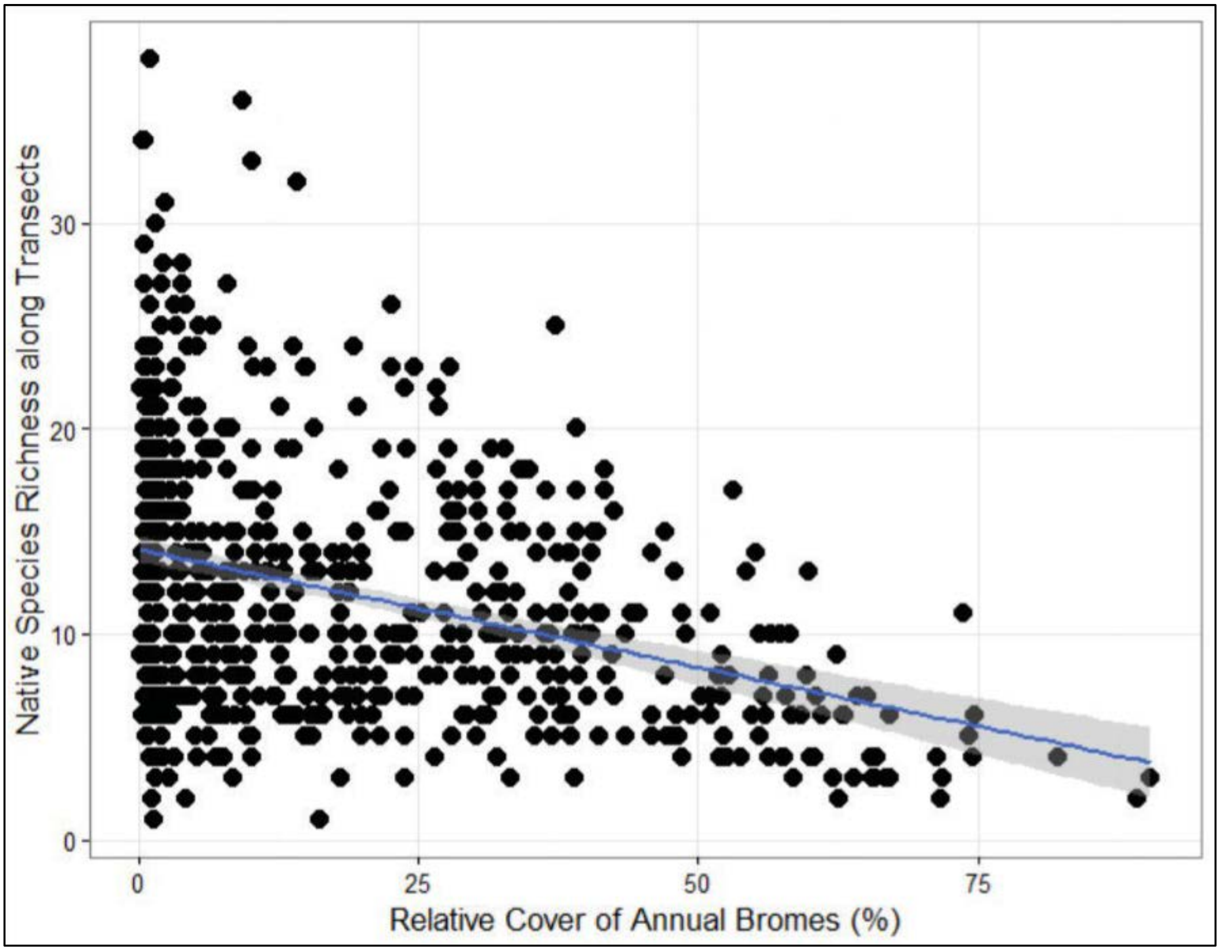

Figure 4.7.5. The relationship between native species richness and the relative cover of annual bromes in long-term monitoring plots in National Park units of the Northern Great Plains for 1998 to 2015 (Ashton and Davis 2016).

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: Plains Cottonwood Stand Seral Stage

Since the mid to late 1880’s, riparian forests have expanded along the North Platte as a result of the construction of dams and the resulting changes in water flow (Johnson 1994). Willows and cottonwoods have thrived because low flows in June allow for sufficient recruitment and lower peak flows and reduced ice scour reduce tree mortality. Seral stage is an intermediate stage of ecological succession; vegetation communities in disturbed areas are at a seral stage.

Measure of Upland Riparian Community Structure and Composition: Percent of 20 Riparian Plots with Native Deciduous Seedlings

The percent of seedlings in the riparian zone indicates successful recruitment since reproduction. This demographic measure can be incorporated into quantitative population analyses in the future.

Reference values were based on descriptions of historic condition and variation, past studies, and/or management targets. Current park 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," or TBD, 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 (2016).

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

Status and Trends in Community Composition and Structure of FOLA Prairies

We found 200 plant species from 2011-2015 at FOLA (Appendix A). Graminoids, which includes grasses, sedges, and rushes, accounted for most of the vegetative cover at FOLA, but forbs, shrubs and subshrubs (defined as a low-growing shrub usually under 0.5 meter) were also present (Figure 4.7.6). We found 50 exotic plant species at FOLA, and exotic graminoids were particularly abundant (Figure 4.7.6). The shrubs and subshrubs were all native species.

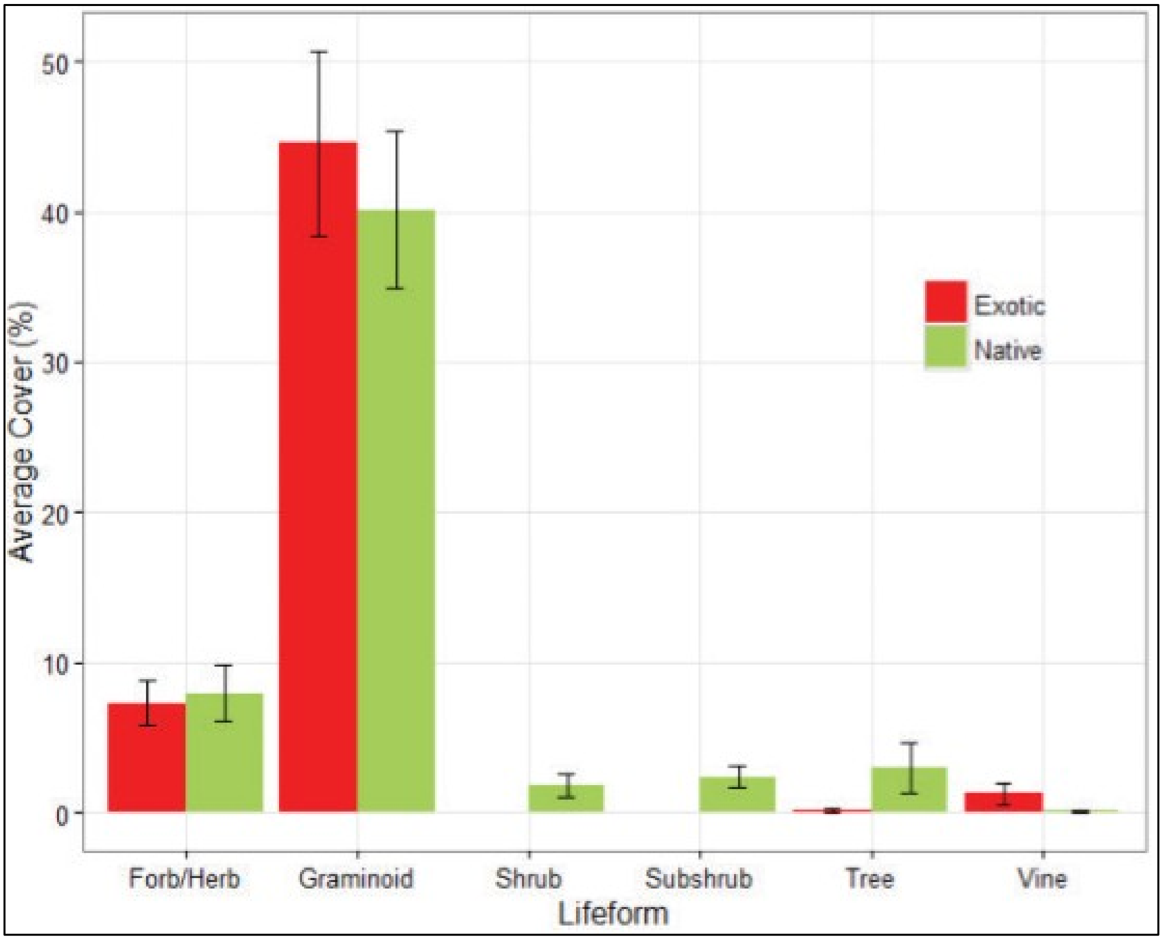

Figure 4.7.6. Average cover by lifeform of native (green) and exotic (red) plants recorded in monitoring plots in Fort Laramie NHS for 2011 to 2015 (Ashton and Davis 2016).

Western wheatgrass (*Pascopyrum smithii*), needle and thread (*Heterostipa comata*), sand dropseed (*Sporobulus cryptandrus*) and blue grama (*Bouteloua gracilis*) were the most abundant native grasses and averaged between 5 and 15% absolute cover (Figure 4.7.7). Cheatgrass (*Bromus tectorum*) and smooth brome (*B. inermis*) were the most pervasive exotics at FOLA. Cheatgrass is a Eurasian, annual grass that has been a part of the Northern Great Plains landscape for more than a century, but its 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). From 2011-2015, the average relative cover of cheatgrass was 25.9 ± 4.4% (mean ± standard error; Figure 4.7.8). Smooth brome is related to cheatgrass, but differs in that it is a perennial grass that was widely planted for forage and along roads.

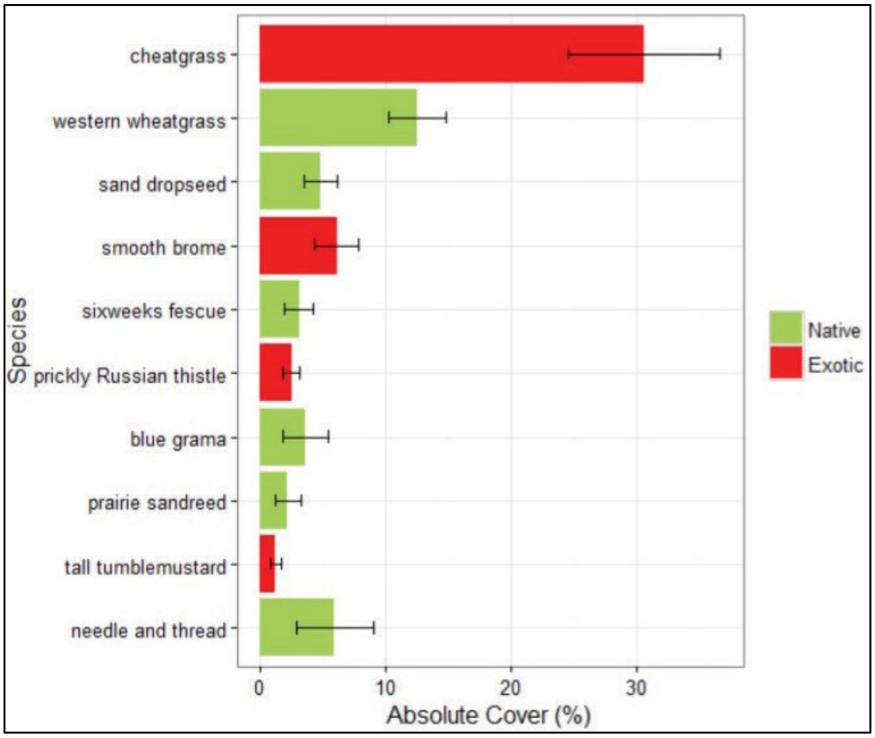

Figure 4.7.7. The average absolute cover of the 10 most common native (green) and exotic (red) plants recorded at Fort Laramie NHS from 2011 to 2015 (Ashton and Davis 2016). Bars represent means ± standard errors.

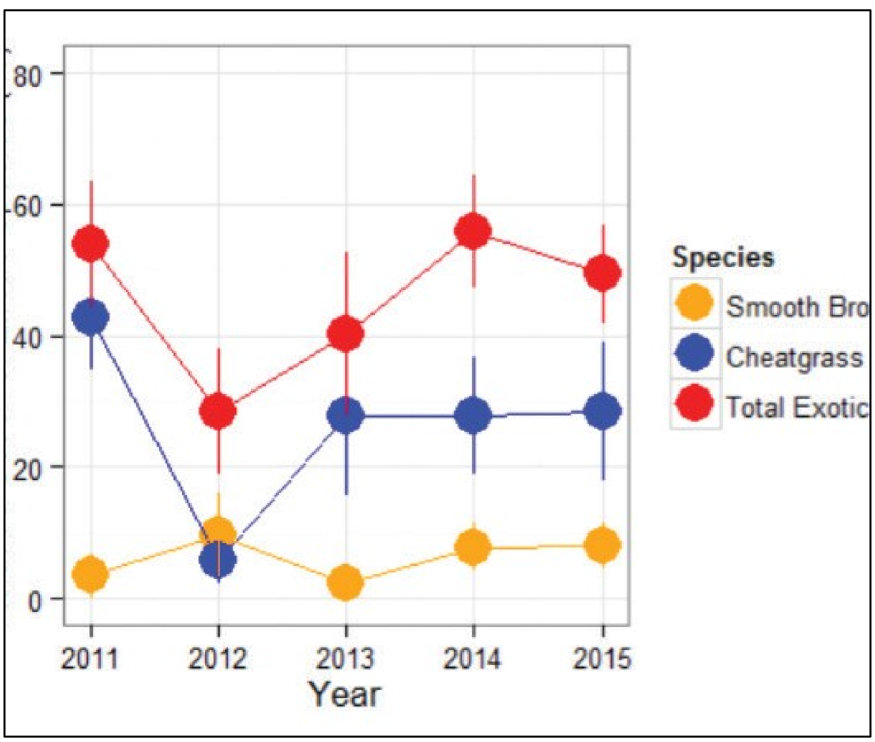

Figure 4.7.8. Trends in the relative cover of exotic plants, smooth brome, and cheatgrass in Fort Laramie NHS from 2011 to 2015 (Ashton and Davis 2016). Points represent means ± standard errors, n=6.

Smooth brome can form monocultures and reduce native plant abundance and diversity, and this may be due in part to its ability alter soil nutrient dynamics (Vinton and Goergen 2006). While smooth brome and cheatgrass were the most abundant, many other exotic species were found yielding an average cover of all exotic species to be 45 ± 4.5%. Maps of cheatgrass and smooth brome occurrence can be found in Appendix B.

It is difficult to distinguish trends from a 5 year dataset, but historical vegetation data from FOLA can provide some evidence of whether exotic cover has changed over time. The vegetation management plan for FOLA (Jones and Tebben 2002) summarized the proportion of plots where exotic species were found in three different surveys completed in 1986 (Olmstead and Perez), 1998 (TNC), and 2000 (Fertig). Table 4.7.3 summarizes the data from Jones and Tebben (2002) and compares it to the proportion of plots where exotic species were found by NGPN. Data is represented as the proportions of plots survey with the target species, because the sample size varied across the years.

Table 4.7.3. Exotic plant species found in vegetation monitoring plots in 1986, 1998, 2000, and 2011-2015. The historic data were copied from Jones and Tebben (2002). The 2011-2015 data were from the NGPN monitoring plots. The values represent the percent of plots where the exotic species was present. An "X" indicates presence within the park.

Scientific name	Common name	1986 (n=16)	1998 (n=32)	2000 (based on species list for park)	2011-2015 (n=15 Or [A] 30 plots)
Agropyron cristatum	Crested wheatgrass [B]	–	6	–	13
Agrostis stolonifera	Creeping bentgrass	–		X	–
Alyssum alyssoides	Pale madwort	–	6	–	–
Alyssum desertorum	Desert madwort	–	–	–	47
Amaranthus blitoides	Mat amaranth	–	–	–	13
Artemisia absinthium	Absintium [A]	–	–	–	3
Artemisia biennis	Biennial wormwood	–	–	–	20
Bromus inermis	Smooth brome [B]	–	34	X	67
Bromus japonicus	Japanese brome [A]	–	22	X	27
Bromus tectorum	Cheatgrass [A]	56	53	X	57
Camelina microcarpa	Littlepod false flax [B]	–	9	–	47
Capsella bursa-pastoris	Shepard's purse	X	–	–	–
Carduus nutans	Musk thistle	–	–	X	–
Chenopodium album	Lambsquarters	–	–	–	7

A. Indicates 2011-2015 species that were surveys in 30 plots (15 plots were typically searched).

B. Those species that appear in a substantially greater proportion of plots in recent years.

Table 4.7.3 (continued). Exotic plant species found in vegetation monitoring plots in 1986, 1998, 2000, and 2011-2015. The historic data were copied from Jones and Tebben (2002). The 2011-2015 data were from the NGPN monitoring plots. The values represent the percent of plots where the exotic species was present. An "X" indicates presence within the park.

Scientific name	Common name	1986 (n=16)	1998 (n=32)	2000 (based on species list for park)	2011-2015 (n=15 Or [A] 30 plots)
Cirsium arvense	Canada thistle [A, B]	–	16	X	30
Cirsium vulgare	Bull thistle	–	–	–	7
Convolvulus arvensis	Field bindweed	–	–	X	27
Cynoglossum officinale	Gypsyflower [A]	–	–	–	20
Descurainia sophia	Herb sophia	–	–	X	67
Echinochloa crus-galli	Barnyardgrass	–	–	–	13
Elaeagnus angustifolia	Russian olive [A]	–	–	X	7
Elymus repens	Quackgrass	38	6	X	33
Eragrostis cilianensis	Stinkgrass	–	–	X	–
Juncus compressus	Roundfruit rush	–	–	–	13
Kochia scoparia	Burningbush, kochia [A, B]	19		X	33
Lactuca serriola	Prickly lettuce	19	6	X	80
Lepidium campestre	Field pepperweed	–	–	–	7
Lepidium perfoliatum	Clasping pepperweed	X	–	–	–
Linaria vulgaris	Butter and eggs	X	–	–	–
Lolium perenne	Perennial ryegrass	X	–	–	–
Medicago lupulina	Black medick	–	–	X	27
Medicago sativa	Alfalfa	–	–	–	13
Melilotus officinalis	Yellow sweetclover [A, B]	–	6	X	43
Nepeta cataria	Catnip	–	3	X	20
Onopordum acanthium	Scotch cottonthistle [A]	–	–	X	37
Pennisetum glaucum	Pearl millet	–	–	X	–
Persicaria maculosa	Spotted ladysthumb	–	–	X	7
Phalaris arundinacea	Reed canarygrass [A*]	–	–	–	10
Phleum pratense	Timothy	25	–	–	13
Plantago major	Common plantain	X	–	–	–
Poa compressa	Canada bluegrass	–	–	–	13

A. Indicates 2011-2015 species that were surveys in 30 plots (15 plots were typically searched).

B. Those species that appear in a substantially greater proportion of plots in recent years.

Table 4.7.3 (continued). Exotic plant species found in vegetation monitoring plots in 1986, 1998, 2000, and 2011-2015. The historic data were copied from Jones and Tebben (2002). The 2011-2015 data were from the NGPN monitoring plots. The values represent the percent of plots where the exotic species was present. An "X" indicates presence within the park.

Scientific name	Common name	1986 (n=16)	1998 (n=32)	2000 (based on species list for park)	2011-2015 (n=15 Or [A] 30 plots)
Poa pratensis	Kentucky bluegrass [B]	25	19	X	40
Polygonum lapathifolium	Curlytop knotweed	–	–	X	–
Polypogon monspeliensis	Annual rabbitsfoot grass	–	–	X	–

A. Indicates 2011-2015 species that were surveys in 30 plots (15 plots were typically searched).

B. Those species that appear in a substantially greater proportion of plots in recent years.

Many of the exotic species we encountered were present in the park in 1986, including cheatgrass, quackgrass, and kochia, at a similar rate as seen in 2011-2015. Since 1986 and 1998, the proportion of plots infested with smooth brome, crested wheatgrass, Canada thistle, prickly lettuce, and prickly Russian thistle has close to doubled. Future monitoring will allow us to better quantify these increases and determine whether they are statistically significant.

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 and in 1 meter^2 and 10 meter^2 quadrats since 2011 (Table 4.7.4).

Table 4.7.4. Average plant species richness in monitoring plots at Fort Laramie NHS from 2011 to 2015 (Ashton and Davis 2016). Values represent means ± one standard error.

Richness category	Point-intercept	1 m^2 quadrats	10 m^2 quadrats
Species richness	14 ± 1.4	7 ± 0.4	12 ± 0.7
Native species richness	9 ± 1.1	4 ± 0.3	7 ± 0.6
Exotic species richness	5 ± 0.6	3 ± 0.2	4 ± 0.3
Graminoid species richness	6 ± 0.5	3 ± 0.2	4 ± 0.2
Forb species richness	6 ± 0.8	3 ± 0.3	6 ± 0.5

While there was some variation across sites, the plots we visited in FOLA tended to have a low 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, prairie dog disturbance, and weather fluctuations (Symstad and Jonas 2011). In FOLA, there is also a mixed history of past land-use practices that have affected current species richness. 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 vary between 3 and 15 species per square meter over the course of 30 years (Symstad and Jonas 2014). Compared to this, FOLA is within the natural range (4 species) but is on the low end of the range. Some sites, such as PCM_002, 003, 070, and 068 (Figure 4.7.1), fall below this reference condition. In contrast, the most diverse plots, FOLA_PCM_069, 011, 09 (Figure 4.7.9) have greater than 7 native species per square meter.

Figure 4.7.9. A photograph of long-term monitoring plot FOLA_PCM_009, which has a moderate diversity of native plant species (NPS photo).

We did not find any trends in species richness or evenness over time (Figure 4.7.10). Native species richness in 1 meter^2 quadrats was consistent from 2011 to 2015 and ranged from a low in 2012 of 3.2 ± 0.64 (a drought year) to a high of 4.8 ± 1.02 in 2011 (a wet year). From 2011-2015, we recorded between 1 and 20 native species along the point-intercept transects (Figure 4.7.10: top). There was no trend in Peilou's Index of Evenness, J', which measures how even abundances are across taxa (Figure 4.7.10). There is a great deal of variation in species richness and evenness across sites within the park (dashed lines in Figure 4.7.10 represent the maximum and minimum values) which makes detecting long-term trends difficult.

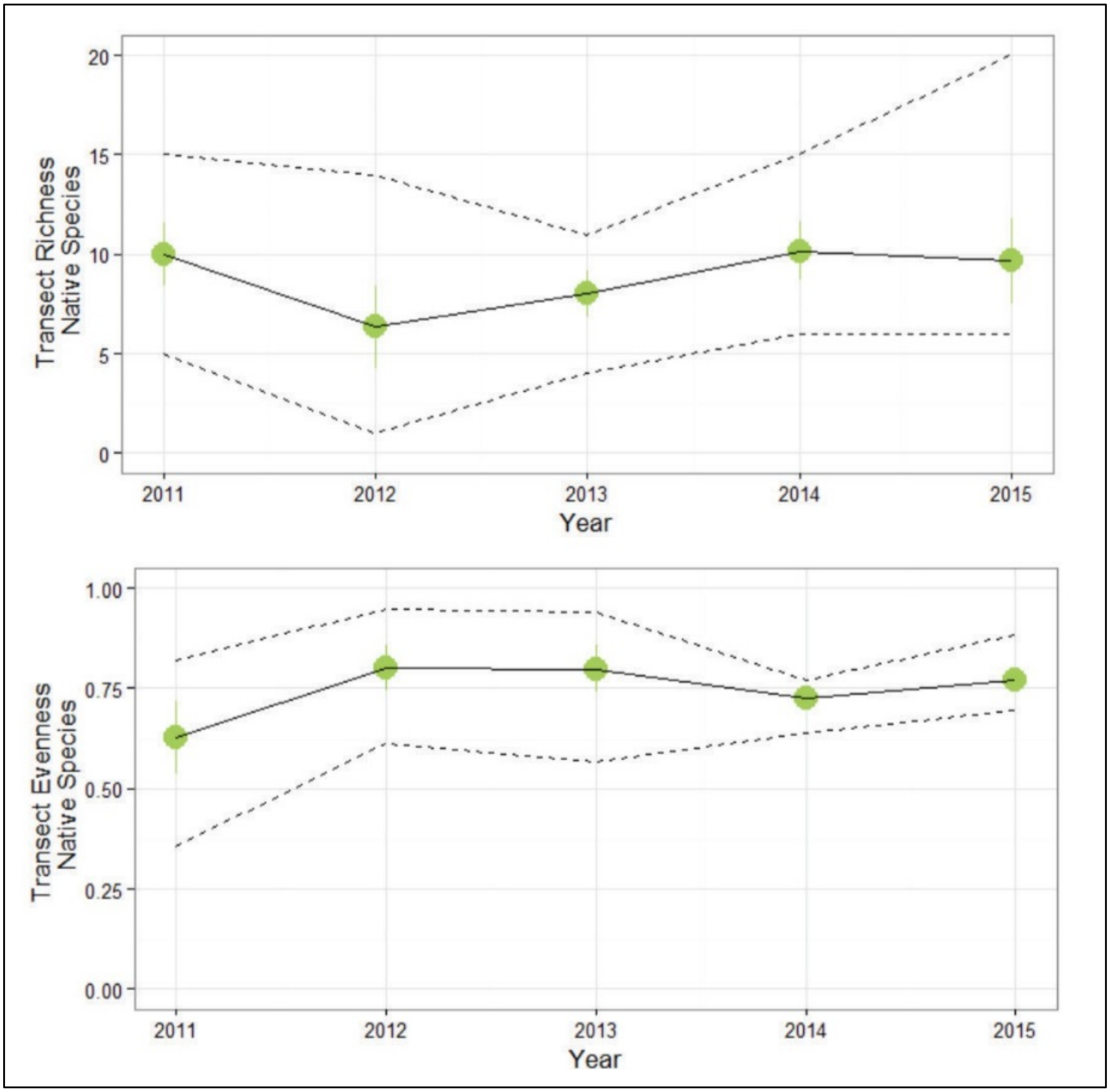

Figure 4.7.10. Trends in native species richness and evenness in Fort Laramie NHS for 2011 to 2015 (Ashton and Davis 2016). Data are means ± one standard error. The dashed line indicates the range of values across the entire data set.

There is evidence from other regions that annual bromes can affect persistence of native species (D'Antonio and Vitousek 2003). In the Northern Great Plains Parks, there is a negative correlation between the cover of annual bromes and native species richness (Figure 4.7.5; $F1, 551 = 36.5$, $P < 0.0001$). If the high cover of annual bromes in FOLA persists or increases, we expect there will be a corresponding decline in native species richness over time.

Disturbance from grazing, flooding, and humans can affect plant community structure and composition in prairie. We measured the approximate area affected by natural and human disturbances at each site we visited between 2011 and 2015. The most common disturbance was from small rodents, but there was also evidence of deer trails, grazing, and flooding. 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

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, Old Fort Laramie, ranged from average minimum monthly temperatures in December of 10.8 °F to maximum monthly July temperatures of 88.4 °F (based on 1981-2010). The 30-year normal annual precipitation totals 15.79 inches. Annual precipitation at FOLA in 2011-2015 was variable and ranged between 6.2 and 17.0 inches, in 2012 and 2015, respectively. There were dry years in the early 2000s, 2006-2008, and in 2012-2013 (Figure 4.7.11). The last two years have been much wetter than average. The native vegetation is adapted to this variation, and productivity responds strongly to increases in summer precipitation (Yang et al. 1998). 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).

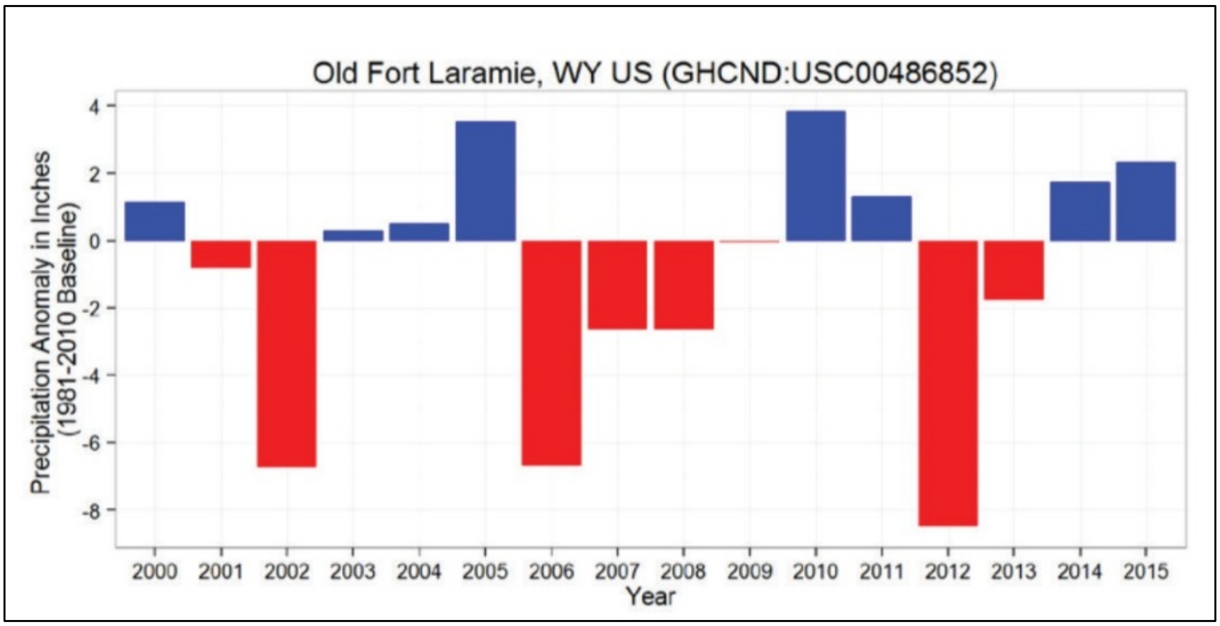

Figure 4.7.11. The total annual precipitation anomaly from 2000 to 2015 for Fort Laramie NHS (Ashton and Davis 2016). Positive values (blue) represent years wetter than and negative values (red) are drier than the 1981-2010 normal. The anomaly is measured in inches and based on data from a nearby weather station.

A longer time series of vegetation data is needed to elucidate trends and correlations with climate because of the large variation in annual temperature and precipitation patterns at FOLA. It is very likely that the large drought in 2012 contributed to the declines in both native species richness

(Figure 4.7.10) and exotic species cover seen in that year (Figure 4.7.8). Native species richness and exotic cover increased in the subsequent wetter years.

Rare Plants

A review of rare plant observations in FOLA was completed in 2000 (Fertig 2000) and a floristic inventory of FOLA was conducted in 2004 (Heidel 2004). While repeating a floristic inventory and locating rare species was not the focus of this study, two rare plant species were observed within vegetation monitoring plots at FOLA.

We identified two rare sedge species, Emory's sedge and Richardson's sedge (*Carex emoryi* and *Carex richardsonii*, respectively) (Figure 4.7.12) in FOLA between 1998 and 2015 (Table 4.7.5). Emory's sedge was observed once in 2013 and Richardson's sedge was observed in 2011 and 2012, and each species was only observed in a single plot. Both species are critically imperiled (S1) in the state of Wyoming, but are globally secure (G5); the result of both species existing on the edge of their global distribution range in Fort Laramie National Historic Site.

Figure 4.7.12. Photographs of two rare species found in plant community monitoring plots at Fort Laramie NHS. Left: Emory's sedge (*Carex emoryi*), a critically imperiled (S1) species in Wyoming. Right: Richard son's sedge (*Carex richardsonii*), an imperiled (S2) species in Wyoming. Photos: Joseph A. Marcus and Andrew Hipp, respectively.

Table 4.7.5. Rare species occurrence in Fort Laramie NHS from 1998 to 2015 (Ashton and Davis 2016). Status ranks are based on Wyoming Natural Diversity Database 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.

Scientific name	Common name	State rank	Global rank	Plot count	Mean cover (%)
Carex emoryi	Emory's sedge	S1	G5	1	0.05
Carex richardsonii	Richardson's sedge	S2	G5	1	0.00

The Status of Riparian Forests in FOLA

In 2014, the NGPN established 20 plots in the forested area along the Laramie River to monitor status and trends in lowland riparian forest condition (Figure 4.7.13).

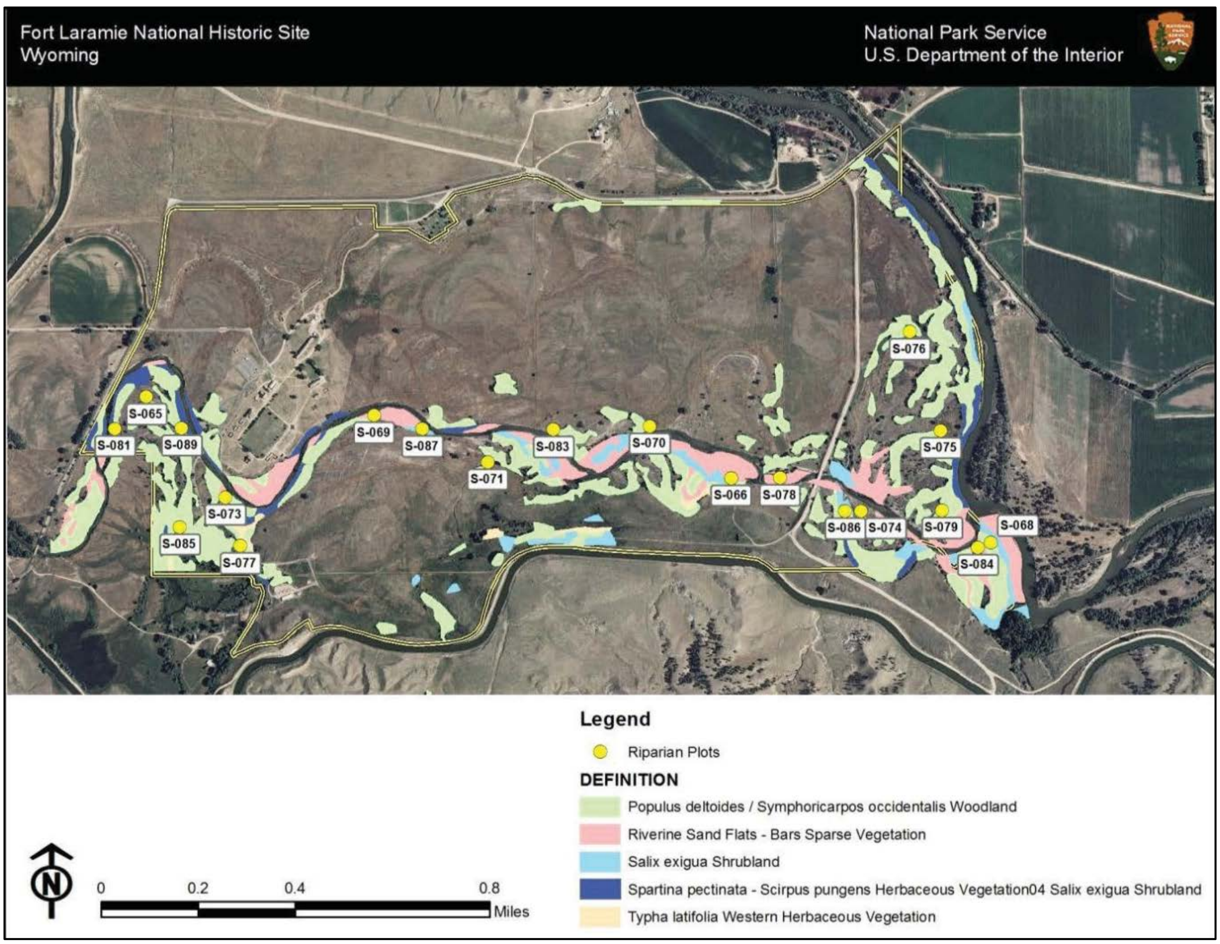

Figure 4.7.13. Map of the plant community types within the riparian area in Fort Laramie NHS and the location of 20 long-term monitoring plots (red) (Ashton and Davis 2016). Vegetation classification is based on the NPS Vegetation Mapping Program report (TNC 1998).

The 2014 data provide a baseline dataset for future surveys; we plan to revisit the same plots every five years (e.g. 2019, 2024, etc.). The riparian lowland forest in Fort Laramie NHS is small (~234 acres), and comprises about 28% of the park. The forest is fairly open and dominated by plains cottonwood (*Populus deltoides*), narrowleaf willow (*Salix exiqua*), and bare sand flats (TNC 1998) The 20 monitoring plots were chosen randomly within the riparian corridor and most fall within the cottonwood community type.

In 2014, we found 9 species of tree or tall shrub in 18 riparian forest plots at FOLA (Table 4.7.6); 2 plots (PCM-083 and 074) did not have any tree or tall shrub species present. Our data were consistent with the 1990's vegetation map and the most common tree species were cottonwood, peachleaf willow, and green ash (Table 4.7.6). Mature cottonwood trees were found in higher average densities than other species (Table 4.7.7). Younger cottonwood trees were also fairly common, but seedlings were found in only 4 sites (Table 4.7.6; Sites: 066, 069, 073, and 087). Mature green ash (*Fraxinius pennsylvanica*) trees were found in only 5 sites (Table 4.7.6), and the average density was less than half that of cottonwood trees (Table 4.7.7). As riparian forests along the North Platte age, cottonwood and willow forests are most often replaced with green ash and box elder (*Acer negundo*) forests (Johnson 1994). In 2014, we found numerous poles and seedlings of green ash, but box elder is still uncommon. Future monitoring is needed to determine if these cottonwood and willow stands will soon become dominated by green ash.

Table 4.7.6. Tree and tall shrub occurrence in 2014 at 20 plots in Fort Laramie NHS (Ashton and Davis 2016).

Scientific name	Common name	Number of plots with trees (DBH > 15cm)	Number of plots with poles (2.5 cm ≤ DBH ≥ 15cm)	Number of plots with seedlings (height < 137 cm)
Populus deltoids	Plains cottonwood	12	8	4
Salix amygdaloides	Peachleaf willow	6	2	2
Fraxinus pennsylvanica	Green ash	5	3	9
Gleditsia triacanthos	Honey locust	1	1	3
Salix fragilis (exotic)	Crack willow	1	0	1
Acer negundo	Boxelder	0	1	1
Prunus virginiana	Chokecherry	0	1	3
Salix exigua	Narrowleaf willow	0	4	6
Shepherdia argentea	Silver buffaloberry	0	2	2

Table 4.7.7. Tree basal area and density by size class for dominant tree and shrub species in the riparian forest of Fort Laramie NH (Ashton and Davis 2016).

Species	Indicator	Value*
Plains cottonwood	Basal area (m^2/ha)	7.18 ± 2.15
	Tree density (stems/ha)	87.54 ± 30.73
	Pole density (stems/ha)	28.66 ± 11.06
	Seedling density (stems/ha)	784.53 ± 544.99
	Snag density (stems/ha)	20.90 ± 14.78
Green ash	Basal area (m^2/ha)	5.86 ± 4.52
	Tree density (stems/ha)	33.94 ± 21.20
	Pole density (stems/ha)	15.92 ± 9.94
	Seedling density (stems/ha)	36.60 ± 11.14
	Snag density (stems/ha)	20.70 ± 14.29
Willow species	Basal area (m^2/ha)	3.89 ± 2.70
	Tree density (stems/ha)	19.24 ± 10.47
	Pole density (stems/ha)	35.03 ± 15.65
	Seedling density (stems/ha)	4048.38 ± 1618.05
	Snag density (stems/ha)	9.55 ± 5.71
Honey locust	Basal area (m^2/ha)	0.01 ± 0.01
	Tree density (stems/ha)	7.96 ± 7.96
	Pole density (stems/ha)	7.96 ± 7.96
	Seedling density (stems/ha)	224.38 ±159.88
	Snag density (stems/ha)	4.78 ± 3.48
Deciduous shrubs	Basal area (m^2/ha)	0.09 ± 0.06
	Tree density (stems/ha)	0.00 ± 0.00
	Pole density (stems/ha)	35.03 ± 28.76
	Seedling density (stems/ha)	1940.38 ± 1537.88
	Snag density (stems/ha)	4.78 ± 3.48
Boxelder	Basal area (m^2/ha)	0.45 ± 0.45
	Tree density (stems/ha)	0.00 ± 0.00
	Pole density (stems/ha)	1.59 ± 1.59
	Seedling density (stems/ha)	1.59 ± 1.59
	Snag density (stems/ha)	0.00 ± 0.00

* Mean across 20 riparian forest monitoring ± standard error of the mean.

Table 4.7.7 (continued). Tree basal area and density by size class for dominant tree and shrub species in the riparian forest of Fort Laramie NH (Ashton and Davis 2016).

Species	Indicator	Value*
Crack willow	Basal area (m^2/ha)	0.03 ± 0.03
	Tree density (stems/ha)	0.40 ± 0.40
	Pole density (stems/ha)	0.00 ± 0.00
	Seedling density (stems/ha)	7.96 ± 7.96
	Snag density (stems/ha)	0.00 ± 0.00

* Mean across 20 riparian forest monitoring ± standard error of the mean.

Since the mid to late 1880's, riparian forests have expanded along the North Platte as a result of the construction of dams and the resulting changes in water flow (Johnson 1994). Willows and cottonwoods have thrived because low flows in June allow for sufficient recruitment and lower peak flows and reduced ice scour reduce tree mortality. We compared our 2014 data to forest composition in the late 1850s to late 1880s (copied from Johnson 1994). The data from the 1850s to late1880s encompasses a greater area and thus a greater number of total trees, but the shape of the histogram reveals that cottonwood and willow age structure in 2014 is fairly similar to the past (Figure 4.7.14). This suggests that new cottonwoods are being established. There were relatively fewer willow trees in the 10 centimeter size class in 2014 than the past. It is unclear, however, if the establishment of young cottonwoods is sufficient to maintain a cottonwood forest in this area. Jones (2007) conducted a survey of riparian forests in Fort Laramie NHS in 2006. He mapped cottonwood seedling and sapling patches along the entire length of the riparian corridor. He found 33 seedlings patches and numerous saplings, but many of the seedlings were root sprouts and it was unclear if these patches were being established frequently enough to maintain cottonwood forests (Jones 2007). Since 2006, there have been a few flood years (e.g. 2010 and 2014) that have likely allowed cottonwood seedlings to germinate and persist. A metric developed to classify cottonwood stand successional status indicates that FOLA riparian areas are primarily composed of late-intermediate seral stage cottonwood stands, indicating at least some cottonwood seedling recruitment is occurring in these plots (Uresk 2015). We plan to resurvey the FOLA riparian plots in 2019 and at that time, we may be able to determine whether cottonwoods are persisting and document effects of the large flood event in 2015.

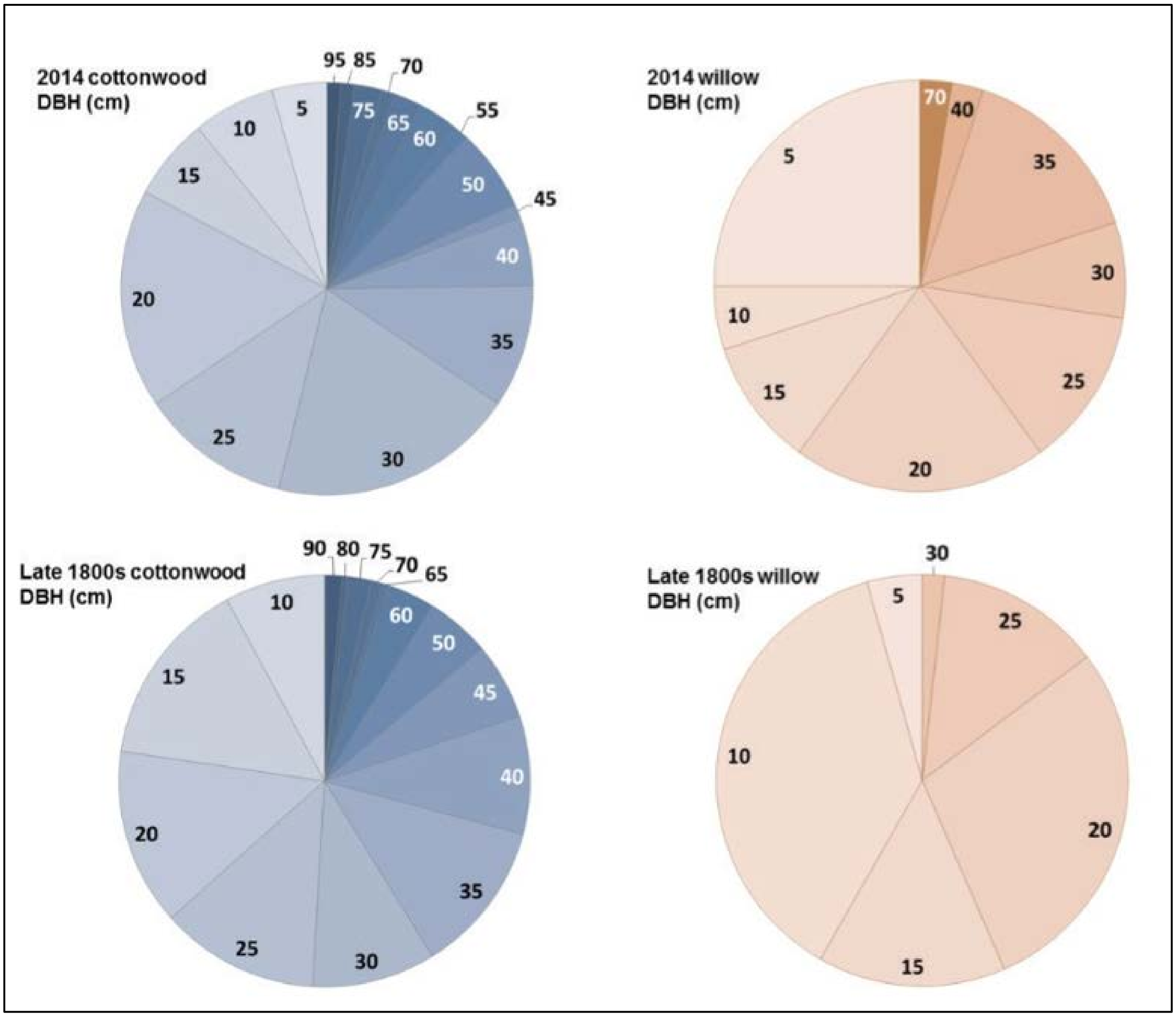

Figure 4.7.14. Size-class proportions of cottonwood (*Populus*) and willow (*Salix*) trees in riparian forests along the North Platte River in Nebraska in the 1850-1880s (bottom panels; from Johnson 1994) and along the Laramie and North Platte River in Fort Laramie NHS (top panel) (Ashton and Davis 2016). Labels in wedges indicate diameter-at-breast-height (DBH) class categories, and each number is the upper limit of that range (e.g., diameter class 10 includes individuals > 5 cm and ≤ 10 cm).

If the goal is to maintain cottonwood forests and willows along this section of the Laramie and Platte Rivers, management interventions such as watering, bank stabilization, and fencing could ensure that the young trees which are currently present survive to maturity.

Exotic Species in Riparian Forests

The understory of the riparian forests in FOLA is a mix of native and exotic grasses and shrubs. The focus of the 2014 survey was woody species, but field crews also surveyed for the presence of exotic species of management concern (e.g. musk thistle, Russian olive) and potential early invaders (Table 4.7.1). Smooth brome (*B. inermis*) is widespread in this area, but the 2014 survey did not include it, probably because it was assumed to be abundant. Canada thistle and prickly Russian thistle were each found in half of the 20 plots (Table 4.7.8). On average, 2 exotic species were found in each plot.

Table 4.7.8. Exotic species detected in 20 riparian plots in Fort Laramie NHS and their corresponding abundance, cover class, and estimated percent cover (Ashton and Davis 2016).

Scientific name	Common name	Number of plots	Average cover class	Estimated cover (%)
Circium arvense	Canada thistle	10	2.50 ± 0.17	1-5
Salsola tragus	Prickly Russian thistle	10	3.20 ± 0.39	1-5
Onopordum acanthium	Scotch cottonthistle	8	2.25 ± 0.25	< 5
Verbascum thapsus	Common mullein	8	2.00 ± 0.19	< 1
Cynoglossum officinale	Houndstongue	5	2.20 ± 0.37	< 5
Bromus japonicas	Japanese brome	3	5.00 ± 0.00	> 25
Bromus tectorum	Cheatgrass	3	4.34 ± 0.67	5-25
Elaeagnus angustifolia	Russian olive	2	2.00 ± 0.00	< 1
Kochia scoparia	Burningbush; kochia	2	2.50 ± 0.50	< 5
Artemisia absinthium	Absinth wormwood	1	2.00 ± 0.00	< 1
Melilotus officinalis	Yellow sweetclover	1	5.00 ± 0.00	> 25
Phalaris arundinacea	Reed canarygrass	1	5.00 ± 0.00	> 25
Sisymbrium altissimum	Tall tumblemustard	1	3.00 ± 0.00	1-5
Tamarix chinensis	Five-stamen tamarisk	1	1.00 ± 0.00	< 1

We did not find any early detection species. Where Japanese brome, reed canarygrass, and yellow sweetclover were found, they were in very high abundance (> 25% cover). The NGP Exotic Plant Management Team (EMPT) is aware of the high density and cover of exotic plants in the riparian forest and much of their control efforts were concentrated in this area during the 2015 field season (Hauk 2016). The EPMT focused on the control of musk thistle, Canada thistle, and Scotch cottonthistle. They have also continued to remove Russian olive and tamarisk as they are found to keep their spread under control.

4.7.4. Conclusion

The Northern Great Plains Inventory & Monitoring Program has been monitoring vegetation in Fort Laramie National Historic Site for 5 years. This report summarizes data from 30 locations from 2011-2015. 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 4.7.9) that summarizes the current status and trends in a few key vegetation metrics.

Table 4.7.9. Summary of vegetation indicators and methods.

Indicator	Measure	2014 Value (mean ± SE)	Reference condition and data source	Condition/trend	Condition rationale
Upland plant community structure and composition	Native species richness (1 m^2 quadrats)	4.3 ± 0.3 species	3-15 species		FOLA plays a vital role in protecting and managing some of the last remnants of native prairie and riparian forests in the region. The park is characterized by low native species richness which should be a moderate concern.
	Native evenness (point-intercept transects)	0.75 ± 0.02	To be determined		Native species richness and evenness vary from year to year, but there is not a significant trend since monitoring began in 2011.
Exotic plant early detection and management	Relative cover of exotic species	45.3 ± 4.5%	< 10% cover		The sites in FOLA had a high cover of exotic species. None of the sites had <10% cover of exotic plants.
	Annual brome cover	25.9 ± 4.4%	< 10% cover		Cheatgrass was the most abundant exotic species, and more research on effective management strategies is greatly needed.
Riparian forest	Plains cottonwood stand seral stage	Late-intermediate seral stage	Mixture of seral stages		The riparian forests of FOLA are currently a mosaic of areas dominated by willow, cottonwood, and ash with an understory of many exotic plants. As cottonwood forests age in FOLA, green ash and box elder are likely to become more dominant.
	Percent of 20 riparian plots with native deciduous seedlings	70%	To be determined		Eight of 20 plots had evidence of young cottonwoods and a majority of plots had large densities of other native tree and shrub seedlings in the understory. Forest surveys will be repeated every 5 years in FOLA and this will allow us to detect trends in condition.
Overall condition for all indicators and measures					–

What is the current status of plant community composition and structure of FOLA grasslands (species richness, cover, and diversity) and how has this changed from 2011-2015?

FOLA plays a vital role in protecting and managing some of the last remnants of native prairie in the area. Native grasses, such as western wheatgrass and needle and thread, are abundant in some sites, but many areas have a high cover of exotic plants. Native plant diversity is at a low level compared to other grasslands in the region (Table 4.7.9), but diversity is spatially variable. We found no significant trends in native diversity or evenness from 1998 to 2015, but both are threatened by the increasing cover of annual bromes (Table 4.7.9). Annual bromes are the most abundant exotic plant species in FOLA and present the largest challenge to FOLA. Continued control efforts will be necessary to maintain native prairie within FOLA.

How do trends in grassland condition correlate with climate?

Native diversity tended to increase in wet years. The large variability in FOLA's climate has made it difficult to discern strong patterns linking temperature, precipitation, and plant community structure (e.g., exotic cover, diversity). A longer time series of vegetation data will make it easier to elucidate trends in the future.

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

We identified 2 rare plant species in FOLA between 2011 and 2015; on of which is considered critically imperiled within Wyoming. These plants are found in such low abundance and in such few plots, it will take many years to determine any trends in rare plant cover. Since to our knowledge, the last rare plant survey was completed in 2004, we recommend targeted surveys of individual rare plant species be considered when funds are available.

What is the composition and structure of the riparian corridor at FOLA?

The riparian corridor in FOLA is a fairly diverse assemblage of cottonwood, willow species, honey locust (*Gleditsia triacanthos*), and green ash. Cottonwoods of all age classes are present (Table 4.7.9).

Exotic species are common in the understory of the riparian forest, and the current control measures may help reduce their abundance in the future. Young cottonwoods have successfully established in 40% of the monitoring plots. This suggests that the successional transition to green ash and box elder dominated forests may be slow.

4.7.5. Vegetation Overall Condition

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

<u>Condition</u>

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 50 points, which placed vegetation at Fort Laramie National Historic Site in the *Warrants Moderate Concern* category.

<u>Confidence</u>

Confidence was Medium for all measures, so the confidence was *Medium* for overall vegetation condition.

<u>Trend</u>

Trend was *Unchanging* for four measures, but two measure did not have enough data for a trend to emerge. The overall trend for vegetation was *Not Available*.

4.7.6. Literature Cited

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4.8. Breeding Birds

Lark bunting are present at Fort Laramie NHS (Photo: USDA photo, Wikimedia Commons 2011).

4.8.1. 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 condition (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 to 1) estimate the proportion 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.

History of Bird Surveys at Fort Laramie National Historic Site

Fort Laramie NHS lists 100 species as "present" in the park, 12 species as "probably present," 74 species as "unconfirmed," and 24 species as "under review" (https://irma.nps.gov/NPSpecies). The first intensive inventory of birds was conducted in the 1980s (Armstrong and Adams 1988) and researchers detected 56 native bird species and three introduced species through "extensive cruises" from 1986–1988. The authors of the resulting publication described the relative distribution of species at the park among habitat types. They also summarized information from nearby areas and previous work, including information from 1858 that reported 211 species near Fort Laramie NHS.

As part of developing the current inventory and monitoring program in the NGPN, bird surveys were conducted in 2002–2004 throughout Fort Laramie NHS (Panjabi 2005). Fifty-five species were detected in point counts and transects during peak breeding, and 67 species were seen overall. In the NGPN group of parks to which Fort Laramie NHS 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 44 permanent point count locations, detecting 63 species in 2013, 63 species in 2014, and 68 species in 2015.

Regional Context

Fort Laramie NHS is located within the Badlands and Prairies Bird Conservation Region (BCR17; Figure 4.8.1). The Badlands and Prairies Bird Conservation Region 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 4.8.2), a species that can be found at Fort Laramie NHS.

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 Badlands and Prairies BCR is stable (Sauer et al. 2003), most 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, which create high quality habitat for many grassland bird species.

Fort Laramie is small, but it contains a variety of habitat types in addition to grasslands (Figure 4.8.3). Riparian woodlands within the park are important bird habitat; loss of riparian habitat is another major cause of bird declines regionally (DeSante and George 1994).

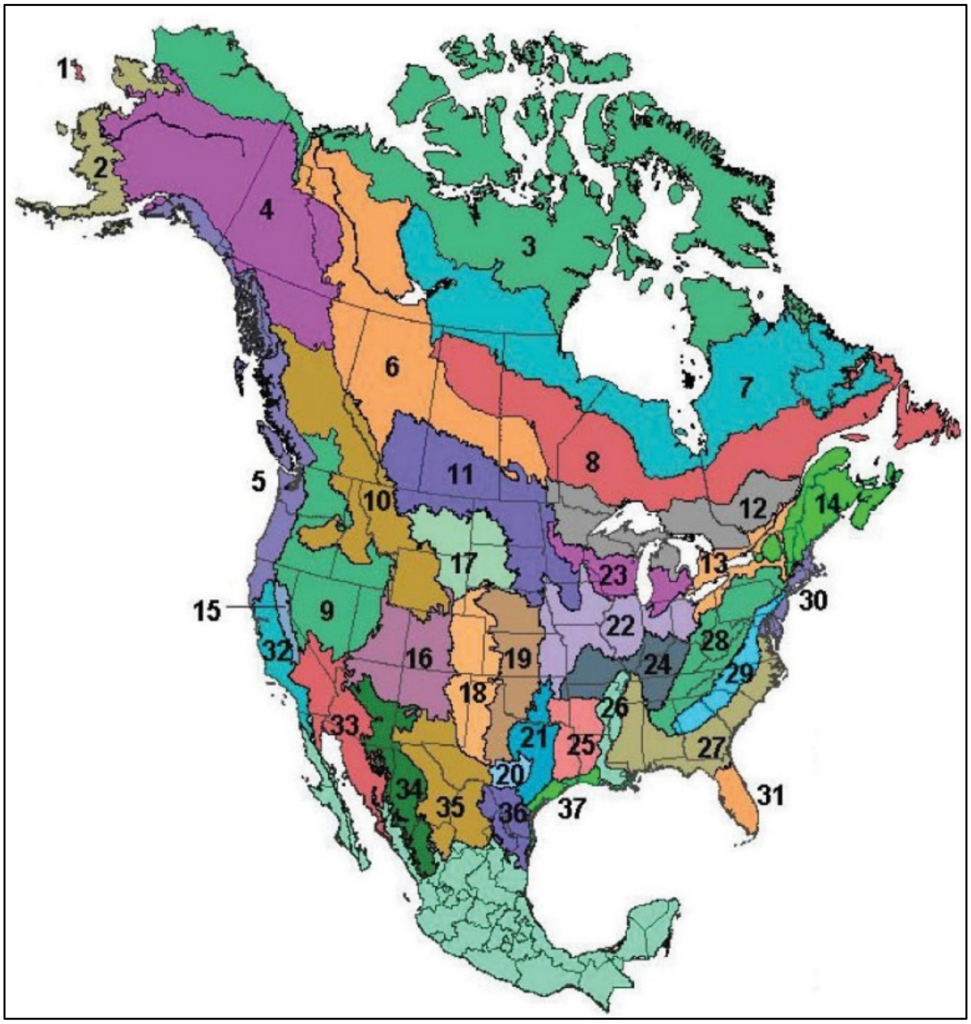

Figure 4.8.1. Bird conservation regions of North America (BCRs; www.nabci-us.org/map.html). Fort Laramie National Historic Site is located within BCR17, the Badlands and Prairies BCR.

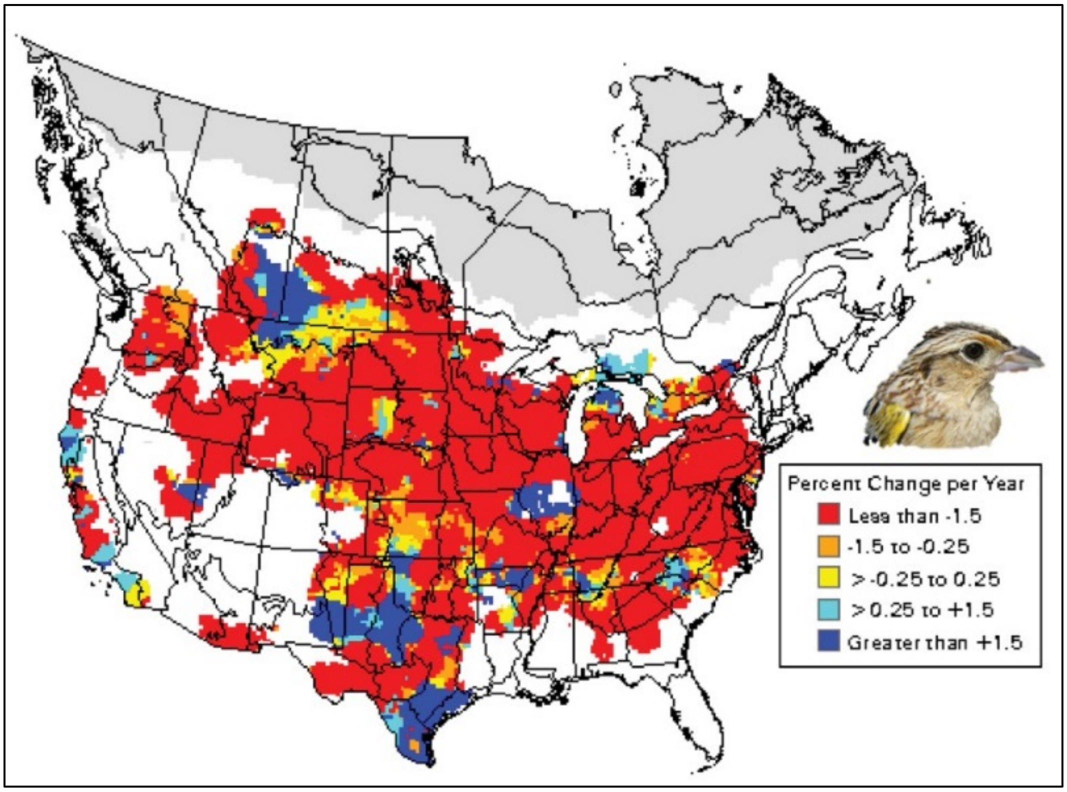

Figure 4.8.2. Population trends for the grasshopper sparrow from 1963 to 2013. The grasshopper sparrow is an example of a grassland species that has been declining for a variety of reasons, including habitat loss and degradation (USGS and BBS, image from Wikipedia).

Figure 4.8.3. Aerial photo of Fort Laramie NHS. Fort Laramie NHS provides diverse habitats for birds and other wildlife (Photo: John Gilpin).

4.8.2. 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 Fort Laramie NHS. Of the 112 species considered to be present or probably present at Fort Laramie NHS, 18 species are considered species of federal concern. However, none of the birds at Fort Laramie NHS are formally protected under the Endangered Species Act. Both bald and golden eagles are protected under the Bald and Golden Eagle Act.

Partners in Flight (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 4.8.4). The red-headed woodpecker and several unconfirmed species at Fort Laramie NHS were identified in the 2014 Yellow Watch List.

Figure 4.8.4. Golden eagles in flight. Based on the Partners in Flight ranking system, the golden eagle was the highest priority species observed at Fort Laramie NHS in 2015 (Photo: NPS photo).

Wyoming’s State Wildlife Action Plan contains a list of species of greatest conservation need. Seven of 80 species designated as species of greatest conservation need can be found at Fort Laramie NHS (Figure 4.8.5). These species include the bald eagle (Tier I, the highest level of conservation need), northern pintail (Tier II), grasshopper sparrow (Tier II), lark bunting (Tier II), sage thrasher (Tier II), Swainson’s hawk (Tier II), and merlin (Tier III).

Figure 4.8.5. Perched lark bunting. The lark bunting is a Wyoming Tier II Species of Greatest Conservation Need frequently observed at Fort Laramie NHS in 2014 (Photo: NPS photo).

4.8.3. 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 has been the same from year to year (2013–present), we used 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 Fort Laramie NHS. 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 BCR 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 Fort Laramie NHS, occupancy estimates (y) can be interpreted as the proportion of the park in which the species is expected to be found. These values can 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 it does not tell us about the identities of the bird species accounted for in these measures. 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. These considerations led us to ask what we know about the conservation value of individual species, or of Fort Laramie NHS as a whole. The Partners in Flight (PIF) database offered 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 NPS Northeast and National Capital 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 Fort Laramie NHS 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 PIF priority rankings (Hunter et al. 1993). Bird species in the PIF database are prioritized at both 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 following Partners in Flight Species Assessment Factors (Panjabi et al. 2012), and these category rankings may be summed to give an overall priority score for the species:

- **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 Partners in Flight 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 is 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 Fort Laramie NHS began in 2013 following a standardized protocol (Beaupré et al. 2013). Forty seven permanent point-transect locations were established in the park, though not all were surveyed each year (Buckland et al. 2001) (Figure 4.8.6). 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 well-sampling groups such as passerines (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 4.8.6. Map of point-transect locations for bird monitoring at Fort Laramie NHS, which includes 47 locations (Buckland et al. 2001). The surveys are located in diverse habitats: riparian woodland, native grassland, pasture, and wetland.

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 Fort Laramie NHS are presented along with a comparison of the same calculations at the level of the bird conservation region. IMBCR has completed full coverage of BCR17, so region-wide estimates are available. The BCR17 results are a combination of data from five states (Table 4.8.1).

Table 4.8.1. The distribution of sampling points among states in the Badlands and Prairies BCR (BCR17).

State	2013	2014	2015
Montana	426	948	315
North Dakota	485	474	371
Nebraska	65	81	80
South Dakota	1799	1037	1197
Wyoming	498	367	690
Total	**3273**	**2907**	**2653**

Occupancy, density, and count data were extracted from the Avian Data Center for using “WY-NGPIM-FL” as the “individual stratum” for Fort Laramie NHS and the “superstratum: BCR17” for BCR17.

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.

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 Fort Laramie NHS is relatively new, having commenced in 2013, so data were not sufficient at the time of this assessment to calculate trends in bird populations.

Overall Breeding Bird Condition, Trend, and Confidence

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

4.8.4. Breeding Bird Conditions, Confidence, and Trends

Species Diversity

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 4.8.2, Figure 4.8.7). Across 47 point-transect locations, 63 species were observed in 2013. Across 44 point-transect locations, 63 species were observed in 2014. Across 43 point-transect locations, 68 bird species were observed in Fort Laramie NHS in 2015. Of these observations, three non-native species were observed from 2013–2015 (Eurasian collared-dove, European starling, and rock pigeon). These introduced species were excluded from richness estimates.

Table 4.8.2. Average species richness of breeding birds at Fort Laramie NHS (FOLA) and within the Badlands and Prairies BCR (BCR17).

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
FOLA	2013	47	63	48	2	34.70 ± 1.93
	2014	44	63	48	3	32.20 ± 1.86
	2015	43	68	49	2	29.84 ± 1.67
BCR17	2013	3273	190	148	5	17.22 ± 0.60
	2014	2907	197	150	5	19.57 ± 0.61
	2015	2653	196	154	5	17.72 ± 0.64

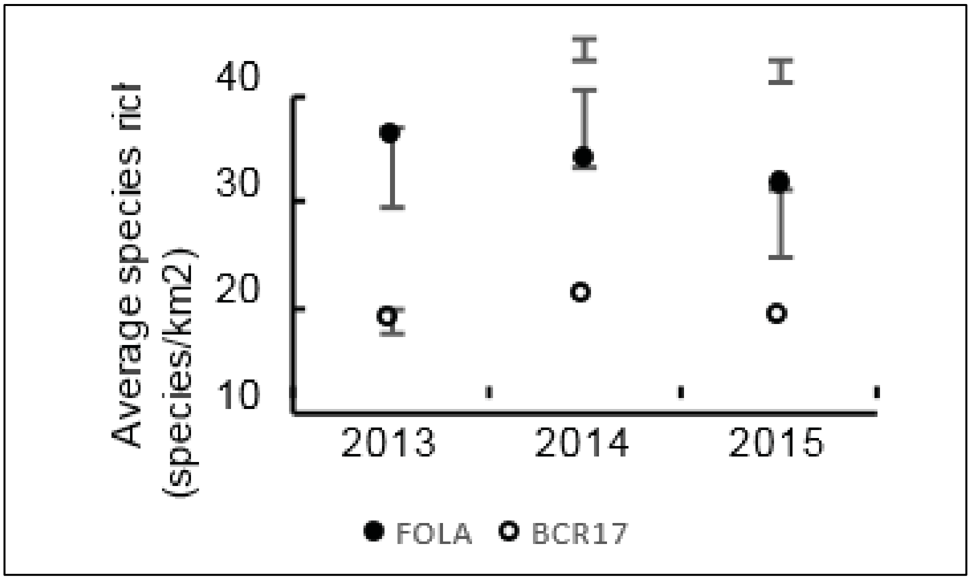

Figure 4.8.7. Average species richness with 95% confidence intervals of breeding birds within Fort Laramie NHS and the Badlands and Prairies BCR (BCR17).

While species richness at Fort Laramie NHS 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 47 locations within the park. The confidence was *High*.

Trend

There were three years of point transect data available from Fort Laramie NHS. A similar number of species was observed in each year, with the greatest number (68) being observed in 2015, and the highest richness estimate 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 4.8.3). We used available density estimates for native species to calculate an average density for the study area (number of birds per square kilometer). In general, density estimates should be fairly sensitive to short-term changes in habitat quality, such as food availability.

Table 4.8.3. Average density of breeding birds at Fort Laramie NHS (FOLA) and within the Badlands and Prairies BCR (BCR17). 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
FOLA	2013	47	63	36	2	–
	2014	44	63	33	3	–
	2015	43	68	52	2	9.09 ± 0.64
BCR17	2013	3273	190	124	5	2.84 ± 0.14
	2014	2907	197	140	5	2.71 ± 0.12
	2015	2653	196	140	5	2.71 ± 0.15

While species abundance at Fort Laramie NHS was three times higher than 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*.

Confidence

Species abundance was calculated from high-quality occupancy estimates from monitoring data from 43 locations within the park. The confidence was *High*.

Trend

There was one year of density estimates available from Fort Laramie NHS. The most abundant bird species in 2015 was the common grackle (57 birds per square kilometer). There were too few years of data available at the time of this assessment to calculate a trend in species abundance.

<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 4.8.4, Figures 4.8.8 and 4.8.9). 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 4.8.4. Conservation value score of native breeding landbirds at Fort Laramie NHS and within the Badlands and Prairies BCR (BCR17).

Location	Year	Number of locations surveyed	Number of species observed	Number of ranked species	Number of non-native species	Average priority ranking ± standard error
FOLA	2013	47	63	50	2	11.20 ± 0.31
	2014	44	63	48	3	11.02 ± 0.28
	2015	43	68	60	2	10.97 ± 0.28
BCR17	2013	3273	190	141	5	11.76 ± 0.22
	2014	2907	197	138	6	11.80 ± 0.22
	2015	2653	196	140	7	11.78 ± 0.22

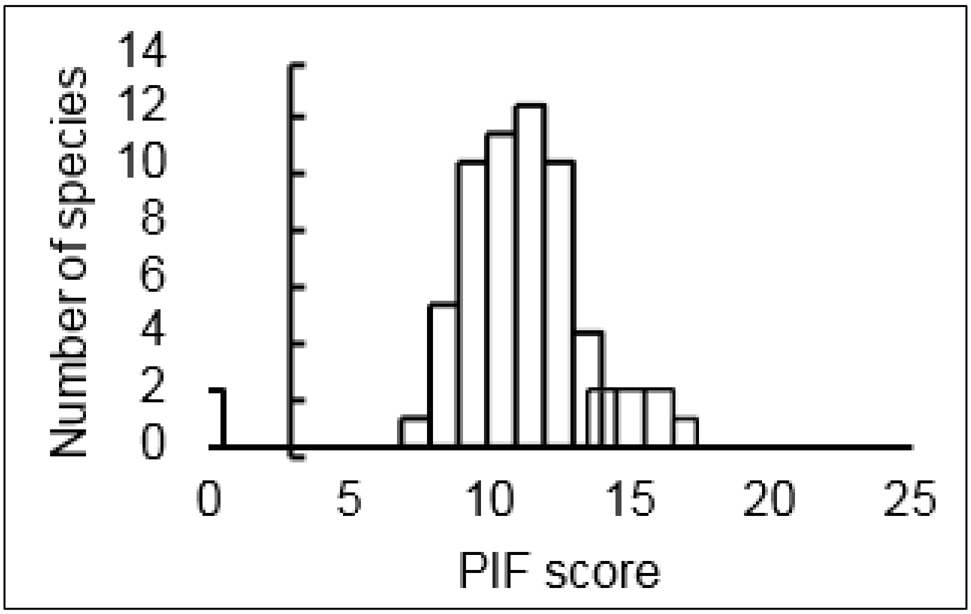

Figure 4.8.8. The distribution of Partners in Flight priority rankings for landbird species seen in 2015 at Fort Laramie NHS. The average ranking was 11.0 ± 0.3 out of a total possible score of 25. We assigned three non-native species a rank of zero. The lowest ranked native species was cedar waxwing with a score of seven. The highest ranked native species was golden eagle with a score of 17.

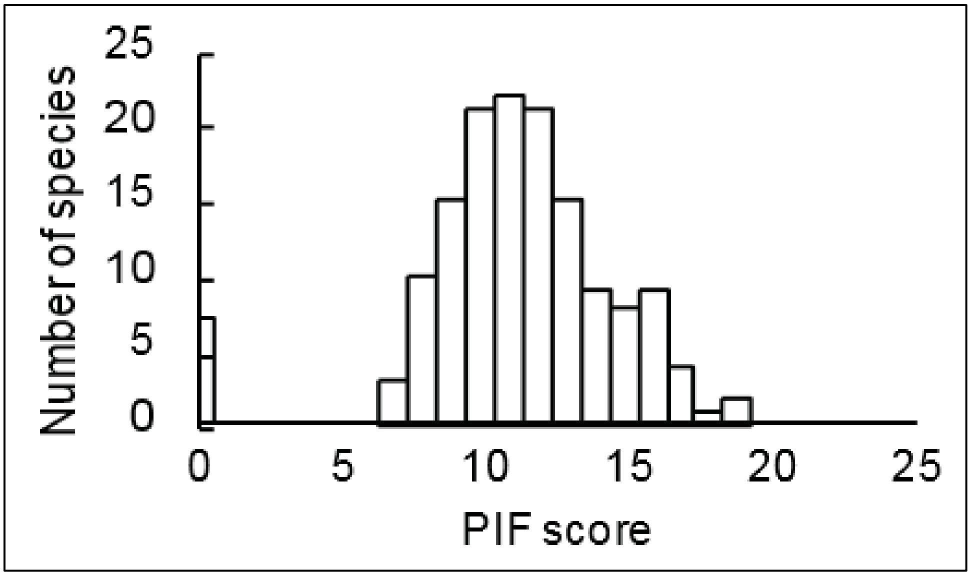

Figure 4.8.9. The distribution of Partners in Flight priority rankings for landbird species seen in 2015 within BCR17. The average ranking was 11.8 ± 0.2 out of a total possible score of 25. We assigned seven non-native species a rank of zero. The lowest ranked native species were cedar waxwing, dark-eyed junco, and house finch each with a score of seven. The highest ranked native species were chestnut-collared longspur and greater sage-grouse with scores of 19.

The BCR-wide average priority ranking for all landbirds known to occur was 11.64 (n = 174). In 2013, five landbird species for which PIF rankings were unavailable were reported within the BCR (blackpoll warbler, magnolia warbler, Tennessee warbler, white-winged crossbill, and yellow-throated vireo). In 2014, five landbird species for which PIF rankings were unavailable were reported within the BCR (American pipit, fox sparrow, ruby-throated hummingbird, Wilson's warbler, and yellow-throated vireo). In 2015, seven landbird species for which PIF rankings were unavailable were reported within the BCR (Alder flycatcher, American tree sparrow, Bewick's wren, fox sparrow, pileated woodpecker, Townsend's warbler, and western scrub-jay).

While conservation values at Fort Laramie NHS 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 47 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

PIF 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 available at the time of this assessment to calculate a trend in these parameters.

Breeding Birds Overall Condition

Table 4.8.5. Breeding birds 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		

We did not assign an overall breeding bird condition to birds at Fort Laramie NHS, due to a lack of clear or accepted standards for doing so. 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 bird condition was *Not Available* for Fort Laramie NHS (Table 4.8.6).

Table 4.8.6. 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 32.25 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 in 2015 was 9.09 birds/km^2. 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 Fort Laramie NHS, 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 priority species observed at Fort Laramie NHS in 2015 were golden eagle, grasshopper sparrow, vesper sparrow, northern flicker, and red-headed woodpecker. The grasshopper sparrow was the most abundant and widely distributed of these species (Table 4.8.7).

Table 4.8.7. Occupancy and density estimates for the top-ranked priority species in Fort Laramie NHS 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 Fort Laramie NHS. There were not sufficient data to generate estimates for the golden eagle, vesper sparrow, or red-headed woodpecker.

Common name	RCS--b	Count	Psi	% CV	D	% CV	N
Golden eagle	17	1	–	–	–	–	–
Grasshopper sparrow	16	9	0.418	56	35.25	34	423
Vesper sparrow	16	2	–	–	–	–	–

Table 4.8.7 (continued). Occupancy and density estimates for the top-ranked priority species in Fort Laramie NHS 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 Fort Laramie NHS. There were not sufficient data to generate estimates for the golden eagle, vesper sparrow, or red-headed woodpecker.

Common name	RCS--b	Count	Psi	% CV	D	% CV	N
Northern flicker	15	7	0.578	51	0.15	108	2
Red--headed woodpecker	15	1	–	–	–	–	–

Breeding Bird Survey (BBS) 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. Golden eagles, grasshopper sparrows, and vesper sparrows have experienced regional declines (Figures 4.8.10, 4.8.11, and 4.8.12).

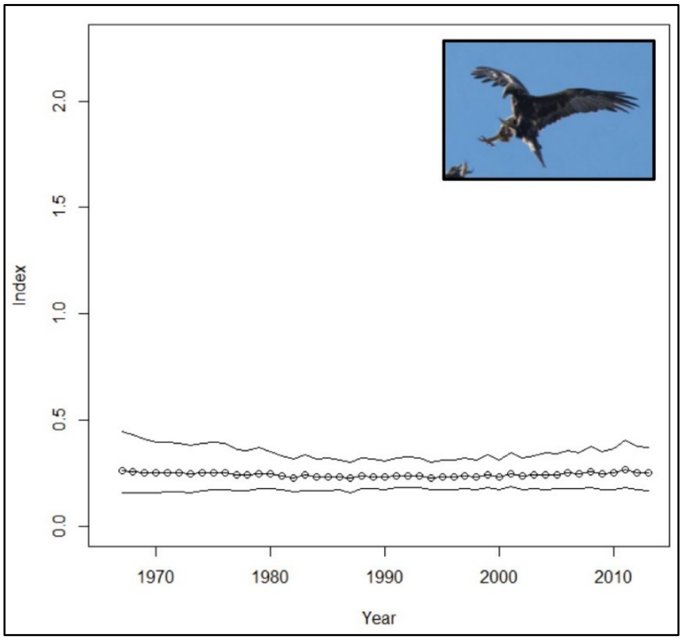

Figure 4.8.10. Changes in the relative abundance index for golden eagles from 1968 to 2013 within the Badlands and Prairies BCR (Sauer et al. 2014). The golden eagle has remained stable to decreasing, albeit insignificantly decreasing (-0.09% annual decrease, 95% credible interval: -3.6 to -1.2). Dots indicate observations, solid lines are 95% credible interval.

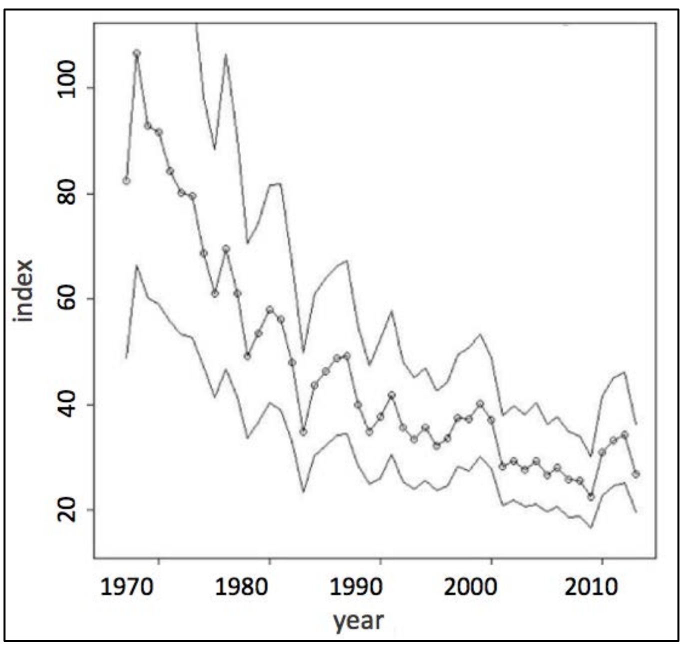

Figure 4.8.11. Changes in the relative abundance index for the grasshopper sparrow from 1968 to 2013 within the Badlands and Prairies BCR (Sauer et al. 2014). The grasshopper sparrow has experienced a 2.4% (95% credible interval: -3.6 to -1.2) annual decline. Dots indicate observations, solid lines are 95% credible interval.

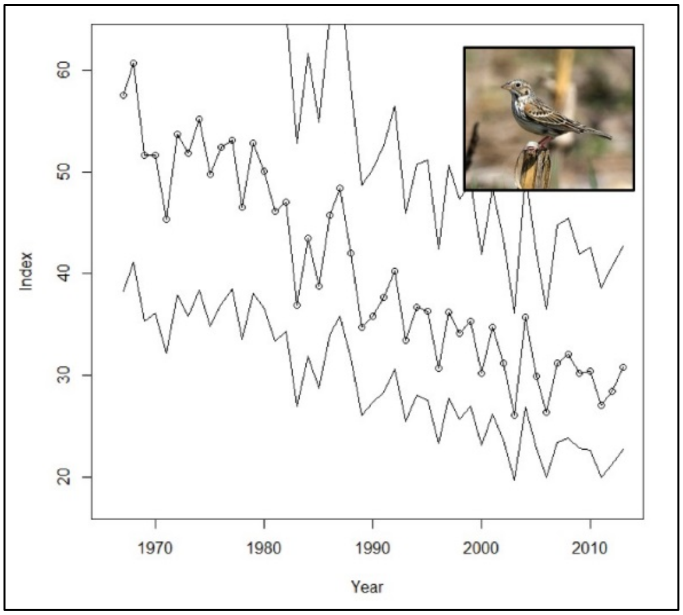

Figure 4.8.12. Changes in the relative abundance index for the vesper sparrow from 1968 to 2013 within the Badlands and Prairies BCR (Sauer et al. 2014). The vesper sparrow has experienced a 1.4% (95% credible interval: -2.3 to -0.4) annual decline. Dots indicate observations, solid lines are 95% credible interval.

The regional trends presented below show all available data for each species within BCR17. The vertical axis represents the relative abundance index, with the point estimate indicated by a circle. The 95% credible interval is indicated by the bounding lines.

Other top-priority species detected during monitoring efforts in the park, but not detected in 2015 include: northern harrier, lark bunting, and northern flicker.

4.8.5. 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 contributing to declines. However, it is also clear that some of these introduced species are declining themselves, perhaps due to the same causes of population decline in native species (Figure 4.8.13).

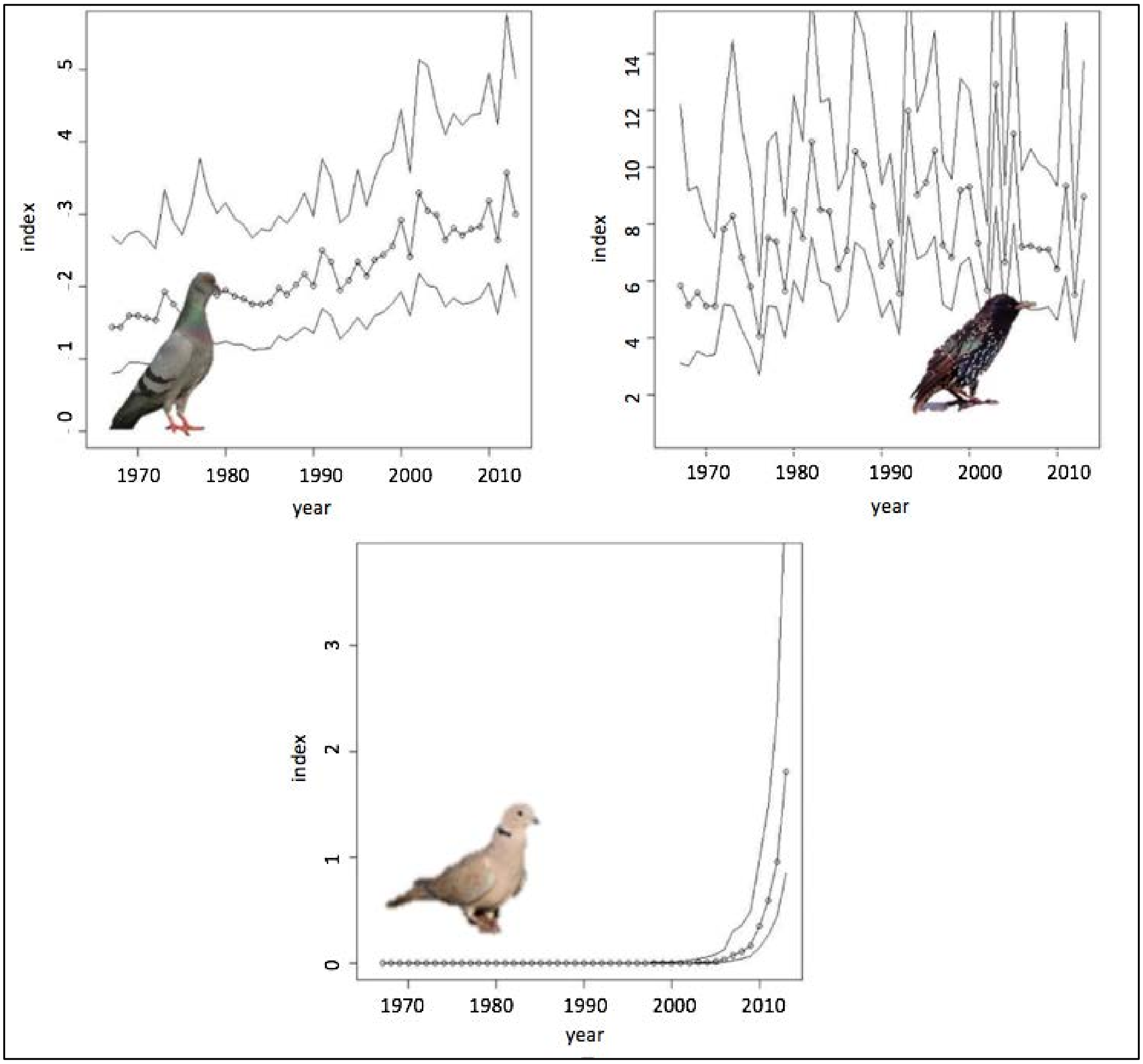

Figure 4.8.13. Region-wide trend data for three non-native species found at Fort Laramie NHS. From the top left: Rock pigeon (PIF rank 9) populations have remained stable to increasing in the Badlands and Prairies BCR. European starling (PIF rank 10) populations have remained stable over the long-term, but may have been decreasing over the last decade. The Eurasian collared-dove (PIF rank 8) has increased significantly in the region.

4.8.6. Data Gaps

The IMBCR surveys were designed 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.

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- Tim O'Connell (Oklahoma State University)

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4.9. Bats

4.9.1. Background and Importance

Bats have many important ecological roles and are one of the most diverse groups of mammals (Nowak and Walker 1994), accounting for about 20% of all mammal species globally (1,200). These winged mammals consume thousands of pounds of insects annually (Cleveland et al. 2006, Boyles et al. 2011), including some damaging agricultural pests, thereby saving billions of dollars in agricultural costs (Boyles et al. 2011). In some regions, bats are critical for the propagation of many plants (Howe and Smallwood 1982, Fujita and Tuttle 1991). Even bat guano (droppings) provides unique habitat to some specialist organisms (Mulec et al. 2016). Some bats are considered by researchers to be keystone species (Mello et al. 2015), a species that has a much greater effect on its ecosystem than would be expected given its biomass, and can be bioindicators of the health of a broad range of organisms (Jones et al. 2009).

Bats have not benefited from the charismatic appeal associated with many other organisms (Martin-Lopez et al. 2007) and have suffered population declines (Frick et al. 2010) due white nose syndrome (WNS), a disease accompanied by a distinctive white fungal growth across the nose and muzzle of infected bats. White nose syndrome is an exotic disease first documented in New York State and most likely originating in Europe (Warnecke et al. 2012). The disease is now widespread throughout eastern and central North America and, at the time of this assessment, had recently been identified in a small brown bat (*Myotis lucifgus*) in Cascade Mountains of northwestern Washington State.

National Park Service lands are important reference and monitoring sites for bat populations. The NPS is dedicated to protecting bats and their habitat; at the time of this assessment, over 40 parks were host to at least 43 projects to protect bats and gain insight into white nose syndrome (NPS 2015). Among NPS units that have caves, mines, and old buildings for roosting, about 40 of the 47 bat species resident in the United States occur on NPS land (NPS 2015).

Regional Context

Eighteen bat species—of which 13 are fully resident, three are resident in the summer, and two are suspected residents—are known to occur in Wyoming (Table 4.9.1) (Orabona et al. 2012; I. Abernethy, personal communication, 24 August 2016). Many of these bats are of particular concern to the state and are listed as high priority Species of Greatest Conservation Need in the Wyoming State Wildlife Action Plan (Wyoming Game and Fish Department (WGFD) 2010).

Table 4.9.1. Bats found in Wyoming and resident status (Orabona et al. 2012). Conservation status is included for species of concern at state and/or federal status (Abernathy et al. 2015). At the state level, species may be classified as Species of Greatest Conservation Need (SGCN) by Wyoming Game and Fish Department, where Tier I is the highest priority and III is the lowest, or by Bureau of Land Management (BLM) sensitivity ratings specific to the state. Federal designations include those overseen by the US Fish and Wildlife Service (USFWS) under the Endangered Species Act (ESA). The USDA Forest Service (USFS) also assigns sensitive status on a regional scale; Fort Laramie NHS is in Region 2 (Rocky Mountain Region).

Scientific name	Common name	Resident status	Conservation status
Antrozous pallidus	Pallid bat	Resident	SGCN III (WYGFD)
Corynorhinus townsendii pallescens	**Townsend's big-eared bat[A]**	Resident	SGCN I (WYGFD), Sensitive (BLM), Sensitive (Region 2, USFS)
Eptesicus fuscus	**Big brown bat[A]**	Resident	SGCN II (WYGFD)
Euderma maculatum	Spotted bat	Resident	SGCN II (WYGFD), Sensitive (BLM), Sensitive (Region 2, USFS)
Lasiurus borealis	**Eastern red bat[A]**	Summer resident	SGCN II (WYGFD)
Lasiurus cinereus	**Hoary bat[A]**	Summer resident	Sensitive (Region 2, USFS)
Lasionycteris noctivagans	**Silver-haired bat[A]**	Summer resident	–
Myotis californicus	California myotis	Resident	–
Myotis ciliolabrum	**Western small-footed myotis[A]**	Resident	SGCN II (WYGFD)
Myotis evotis	**Long-eared myotis[A]**	Resident	SGCN II (WYGFD), Sensitive (BLM)
Myotis lucifugus	**Little brown myotis[A]**	Resident	SGCN II (WYGFD); Petitioned for ESA listing
Myotis septentrionalis	Northern myotis	Resident	SGCN II (WYGFD); Threatened (USFWS)
Myotis thysanodes	**Fringed myotis[A]**	Resident	SGCN II (WYGFD), Sensitive (BLM), Sensitive (Region 2, USFS)

[A] Species known or suspected to be present at Fort Laramie NHS, also shown in bold text.

[B] Geographic range of tri-colored bat has been expanding westward. Tri-colored bats have been observed hibernating near Torrington, Wyoming, approximately 30 kilometers (19 miles) southeast of Fort Laramie NHS (I. Abernathy, personal communication, 24 August 2016).

Table 4.9.1 (continued). Bats found in Wyoming and resident status (Orabona et al. 2012). Conservation status is included for species of concern at state and/or federal status (Abernathy et al. 2015). At the state level, species may be classified as Species of Greatest Conservation Need (SGCN) by Wyoming Game and Fish Department, where Tier I is the highest priority and III is the lowest, or by Bureau of Land Management (BLM) sensitivity ratings specific to the state. Federal designations include those overseen by the US Fish and Wildlife Service (USFWS) under the Endangered Species Act (ESA). The USDA Forest Service (USFS) also assigns sensitive status on a regional scale; Fort Laramie NHS is in Region 2 (Rocky Mountain Region).

Scientific name	Common name	Resident status	Conservation status
Myotis volans	**Long-legged myotis**[A]	Resident	SGCN II (WYGFD)
Myotis yumanensis	Yuma myotis	Suspected resident	–
Nyctinomops macrotis	Big free-tailed bat	Accidental	–
Perimyotis (Pipistrellus) subflavus subflavus	**Tri-colored bat**[A]	Suspected resident[B]	Petitioned for ESA listing

[A] Species known or suspected to be present at Fort Laramie NHS, also shown in bold text.

[B] Geographic range of tri-colored bat has been expanding westward. Tri-colored bats have been observed hibernating near Torrington, Wyoming, approximately 30 kilometers (19 miles) southeast of Fort Laramie NHS (I. Abernathy, personal communication, 24 August 2016).

Fort Laramie NHS is confirmed as home to at least six species of bat, is suspected to host an additional five species (Licht 2016), and could host more species at certain times of the year. Of the 11 species confirmed or suspected in the park, eight have special status from the State of Wyoming (WGFD 2010) and two species (little brown myotis and tri-colored bat) are currently being petitioned for listing under the Endangered Species Act (ESA).

4.9.2. Bats Standards

Wyoming's State Wildlife Action Plan (WGFD 2010) prioritizes eight of the 11 bat species at Fort Laramie NHS for conservation as Species of Greatest Conservation Need (SGCN), but criteria for population size and habitat requirements do not exist. If either of the species currently under consideration for ESA listing are listed as threatened or endangered, then plans will be developed for the recovery of that species.

4.9.3. Methods

Indicators and Measures

We assessed overall bat condition based on the condition of each bat species known or suspected to be present at Fort Laramie NHS, habitat availability, and the status of white nose syndrome in and around the park.

Bat Species

Many bat species share ecological traits and behavioral patterns (e.g., roost during the day, emerge at dusk, hunt using echolocation), but even closely related species can have different roosting preferences, foraging characteristics, and geographic ranges. To gain a full understanding of bat community condition at Fort Laramie NHS, we assessed each bat species as separate indicators. The measures of these indicators were the growth rate of that indicator species and the state and federal levels of concern pertaining to conservation of that species. We describe these measures in detail for Townsend's big-eared bat only, but we apply them to all indicator bat species.

Indicator: Townsend's Big-eared Bat

Townsend's big-eared bat inhabits western North America, from southern Mexico to British Columbia, Canada, and from California to Oklahoma with several more eastern populations in Arkansas and Virginia (Figure 4.9.1) (*Corynorhinus townsendii townsendii*). It is resident year-round but uncommon in Wyoming and is a Tier I Wyoming SGCN (WGFD 2010).

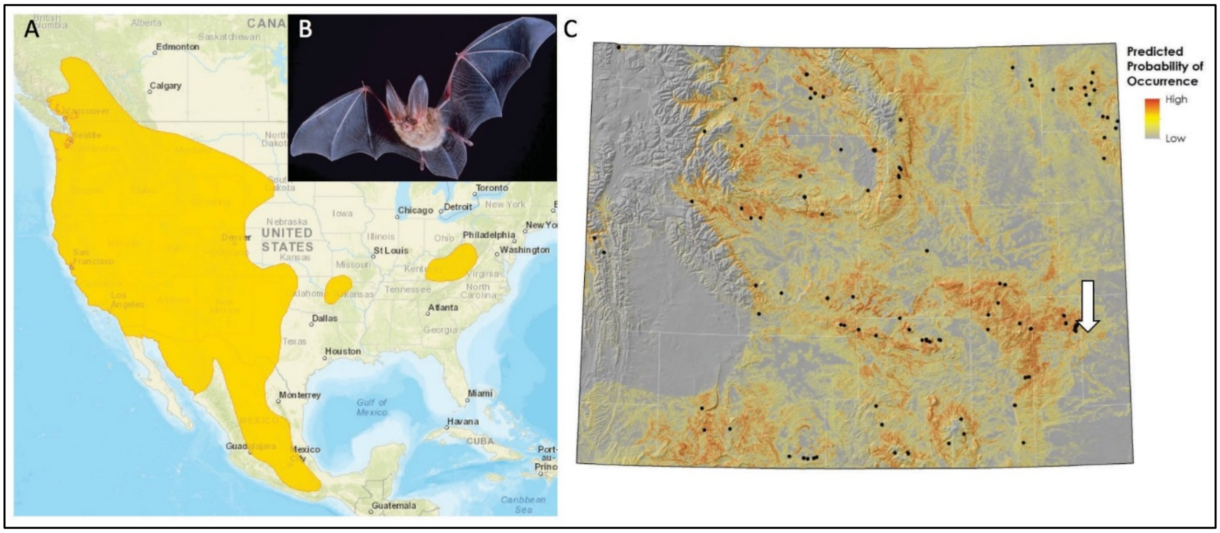

Figure 4.9.1. Distribution and probability of occurrence for the Townsend's big-eared bat. Townsend's big-eared bat is (A) distributed throughout western North America (IUCN 2016) and (B) is identifiable by its large ears (photo courtesy of BLM 2002). The range of this species in Wyoming (C) includes Fort Laramie NHS, indicated by the white arrow (adapted from Abernethy et al. 2015).

Townsend's big-eared bats hibernate in caves and other large, open environments in a variety of ecosystems (WGFD 2010). These bats are sensitive to light and will relocate to a new roosting site if disturbed during the day (Arroyo-Cabrales and Álvarez-Castañeda 2008d). Townsend's big-eared bats can tolerate extremely cold conditions and, therefore, roost in colder environments that may help them to be less susceptible to WNS than other species (I. Abernethy, personal communication, 26 August 2016).

Indicator: Big Brown Bat

Big brown bats (*Eptesicus fuscus*) are resident year-round in Wyoming. This species inhabits North America, Central America, and northern South America (Figure 4.9.2) and at the time of this assessment was a Tier II Wyoming Species of Greatest Conservation Need (SGCN; WGFD 2010), though will not be included as an SGCN in the next State Wildlife Action Plan (I. Abernethy, personal communication, 26 August 2016). Big brown bats are fairly tolerant of cold winter conditions and, at least in part because of this tolerance, are habitat generalists; this species hibernates in various natural and human-made hibernacula (Miller et al. 2008). Individuals roost in buildings, storm sewers, caves, trees cavities, and a variety of other environments (Miller et al. 2008).

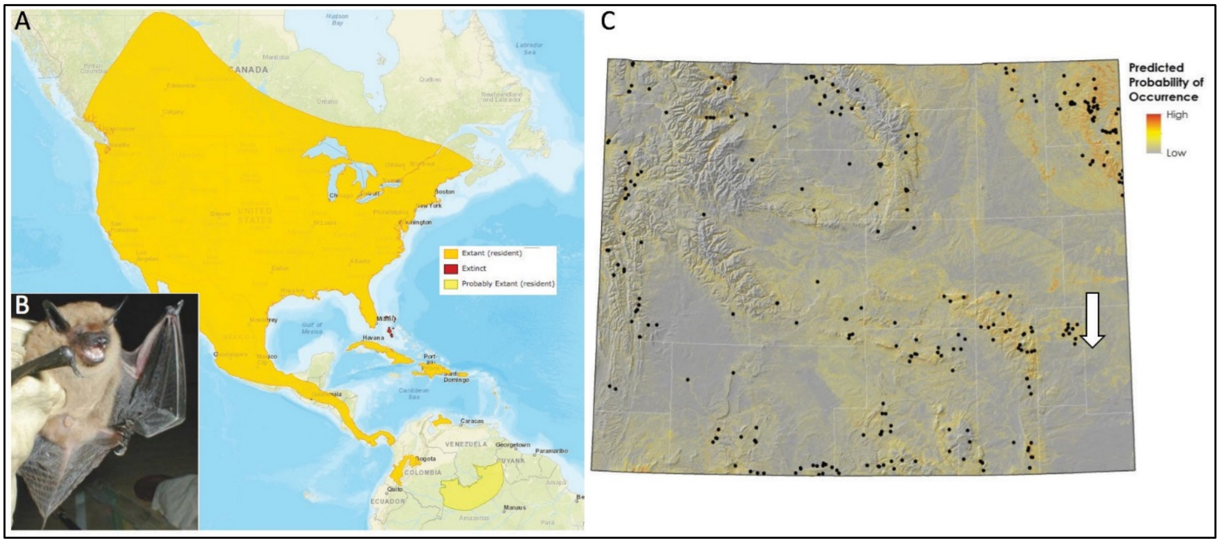

Figure 4.9.2. Distribution and probability of occurrence for the big brown bat. The big brown bat is (A) distributed throughout western North America (IUCN 2016) and (B) has a strong jaw that allows it to forage on a variety of insects (photo courtesy of NPS 2008). The range of this species in Wyoming (C) includes Fort Laramie NHS, indicated by the white arrow (adapted from Abernethy et al. 2015).

Indicator: Eastern Red Bat

Eastern red bats (*Lasiurus borealis*) are migratory bats, summering in Wyoming and moving south to warmer climates in the winter (Orabona et al. 2012, Abernethy et al. 2015). This species inhabits central and eastern North America (Figure 4.9.3) and in Wyoming, where it is relatively uncommon (Abernethy et al. 2015), it is a Tier II Species of Greatest Conservation Need (SGCN). Eastern red bats roost in dense foliage (Arroyo-Cabrales et al. 2016), primarily in hardwood forests but possibly also in riparian corridors (WGFD 2010). This species is vulnerable to habitat loss and wind energy development (WGFD 2010). The eastern red bat may be less susceptible to white nose syndrome than many other bats because it migrates and is active most of the year (I. Abernethy, personal communication, 26 August 2016).

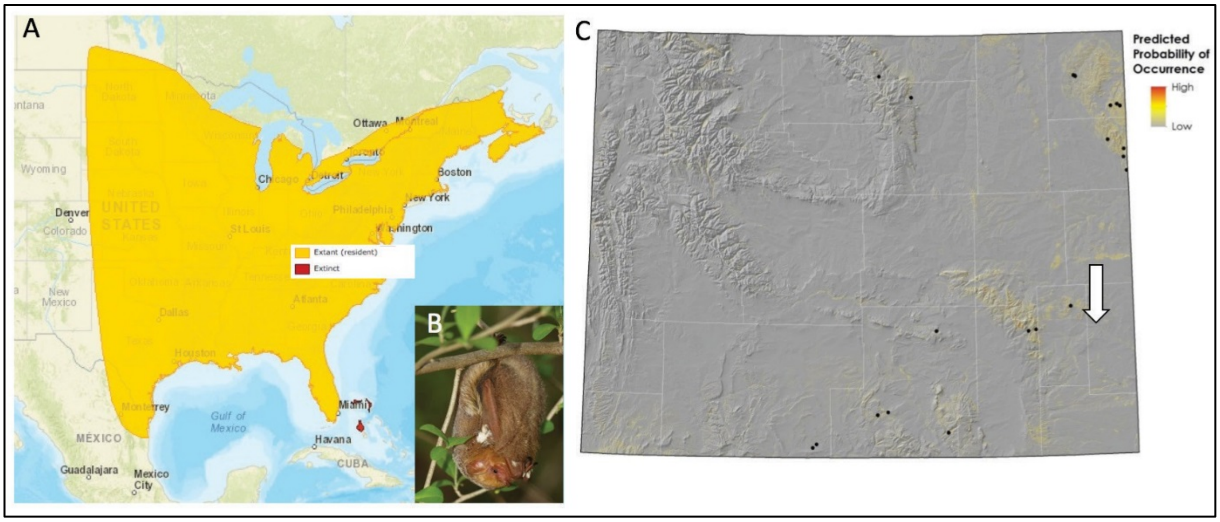

Figure 4.9.3. Distribution and probability of occurrence for the eastern red bat. The eastern red bat is (A) distributed throughout eastern North America (IUCN 2016) and (B) roosts in dense foliage (photo by Chris Harshaw 2010). The range of this species in Wyoming (C) includes Fort Laramie NHS, indicated by the white arrow (adapted from Abernethy et al. 2015).

Indicator: Hoary Bat

The hoary bat (*Lasiurus cinereus*) is widely distributed throughout North and South America (Figure 4.9.4). Hoary bats migrate and are common inhabitants in Wyoming during the summer months. This species tends to roost in dense foliage and may be found in trees at the edge of clearings, though are occasionally deep within forests (Gonzalez et al. 2016). Hoary bats are solitary animals, though will forage in groups (Gonzalez et al. 2016).

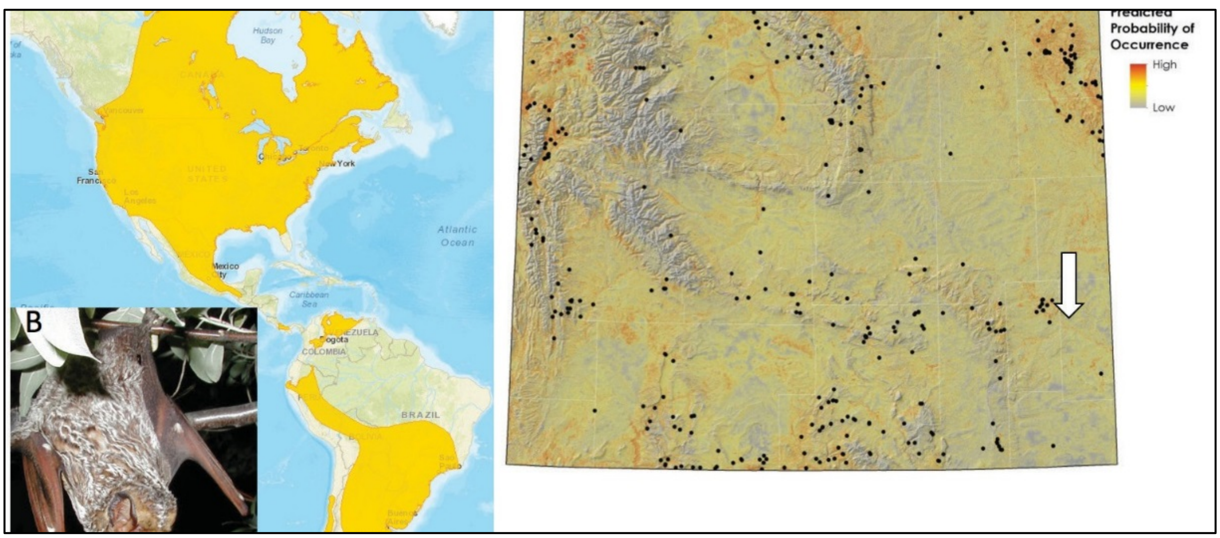

Figure 4.9.4. Distribution and probability of occurrence for the hoary bat. The hoary bat is (A) distributed throughout North and South America (IUCN 2016) and (B) roosts in dense foliage (photo by Paul Cryan 2013). The range of this species in Wyoming (C) includes Fort Laramie NHS, indicated by the white arrow (adapted from Abernethy et al. 2015).

Indicator: Silver-haired Bat

The silver-haired bat (*Lasionycteris noctivagans*) is widely distributed throughout North America (Figure 4.9.5). Silver-haired bats migrate and inhabit Wyoming during the summer months. This species roosts behind loose tree bark and in hollow snags, leaving these sites to forage over short distances to catch moths, flies, and beetles (Arroyo-Cabrales et al. 2008a).

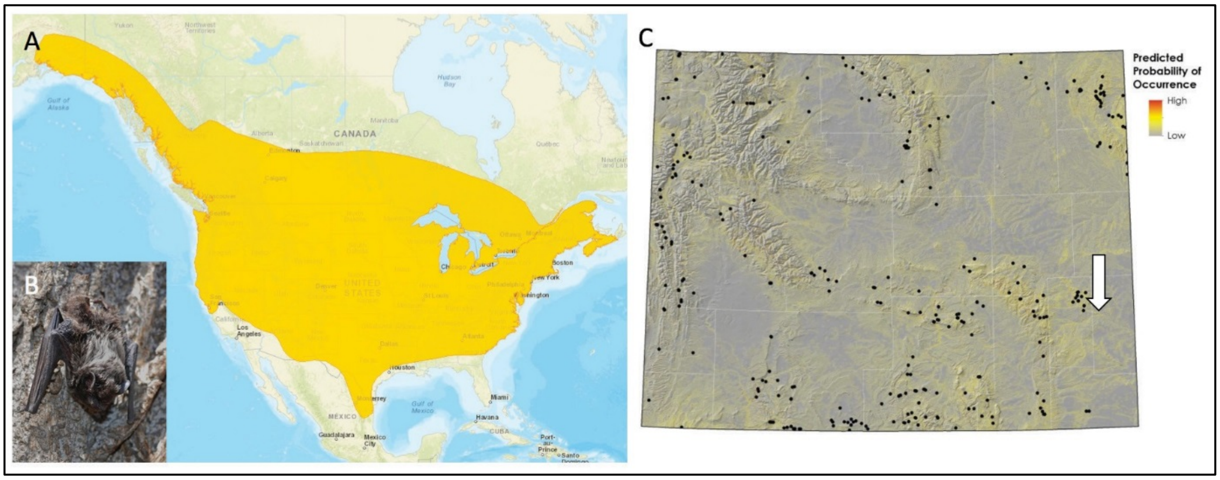

Figure 4.9.5. Distribution and probability of occurrence for the silver-haired bat. The silver-haired bat is (A) distributed throughout North America (IUCN 2016) and (B) roosts in trees, often behind loose bark (photo by Sally King, courtesy of NPS). The range of this species in Wyoming (C) includes Fort Laramie NHS, indicated by the white arrow (adapted from Abernethy et al. 2015).

Silver-haired bats may be less susceptible to white nose syndrome that many other bats because they migrate and are active most of the year (I. Abernethy, personal communication, 26 August 2016).

Indicator: Western Small-footed Myotis

Small-footed myotis (*Myotis ciliolabrum*) is a resident species in Wyoming, where it is a Tier II SGCN. This species inhabits North America, with a range stretching from New Mexico to Alberta (Figure 4.9.6). Associated with a broad range of arid and rocky ecosystems, small-footed myotis tend to use tight crevices and cracks for roosting during the day and will use caves and tunnels for winter hibernacula (Arroyo-Cabrales and Álvarez-Castañeda 2008e). A closely related species, the eastern small-footed myotis (*M. leibii*) are very susceptible to WNS, which may or may not suggest that western small-footed might be too (I. Abernathy, personal communication, 26 September 2016).

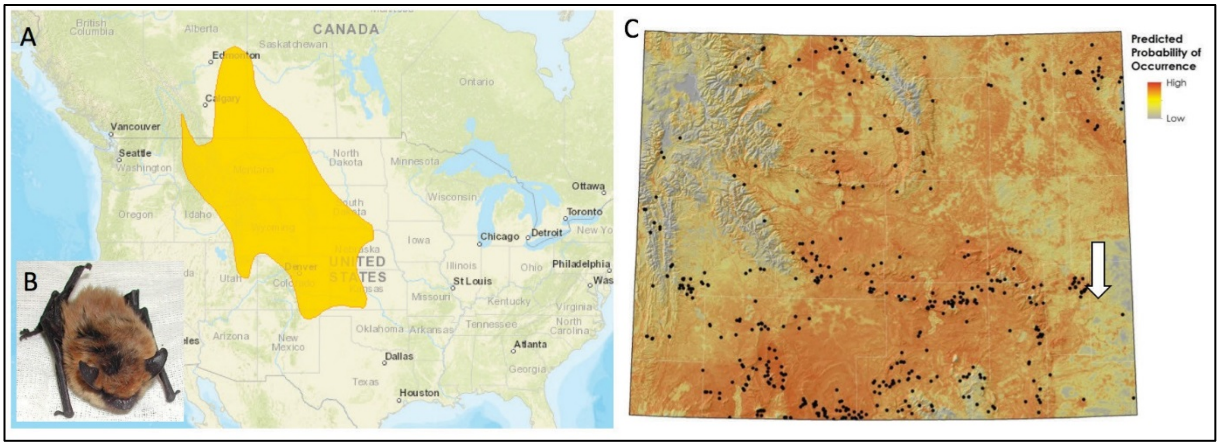

Figure 4.9.6. Distribution and probability of occurrence for the small-footed myotis. The small-footed myotis is (A) distributed throughout North America (IUCN 2016) and (B) is a resident of Wyoming (photo by Drew Stokes, USGS). The range of this species in Wyoming (C) includes Fort Laramie NHS, indicated by the white arrow (adapted from Abernethy et al. 2015).

Indicator: Long-eared Myotis

Long-eared myotis (*Myotis evotis*) are common residents in Wyoming (Abernethy et al. 2015), with a range that stretches from British Columbia to Baja California, Mexico (Figure 4.9.7). Long-eared myotis roost in a variety of cavities and crevices in conifer forests (WGFD 2010), particularly in snags and tree stumps where available (Arroyo-Cabrales and Álvarez-Castañeda 2008a).

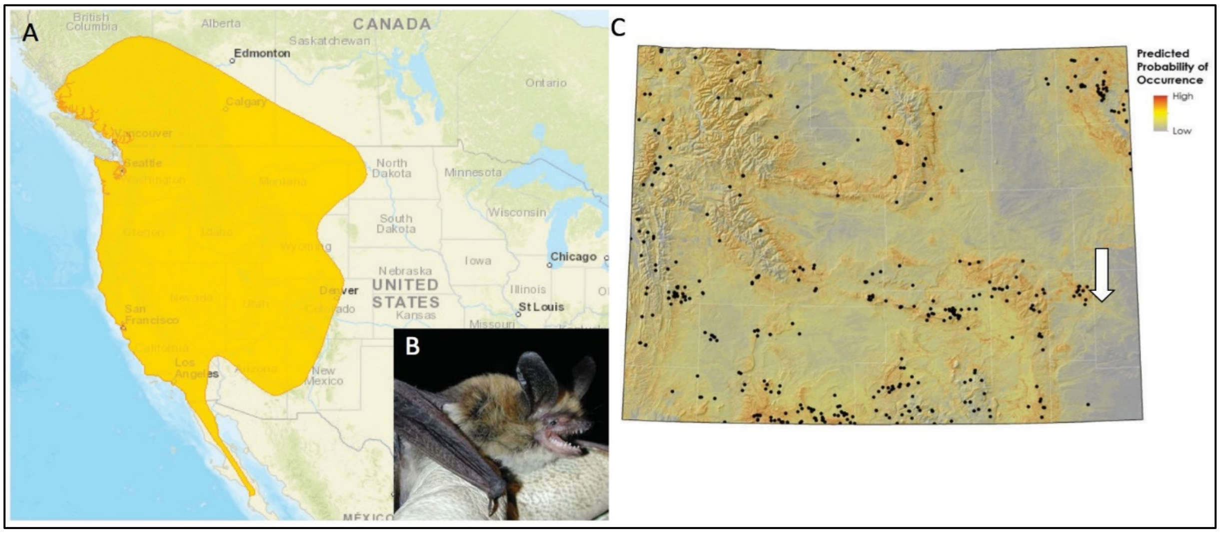

Figure 4.9.7. Distribution and probability of occurrence for the long-eared myotis. Long-eared myotis are (A) distributed throughout North America (IUCN 2016) and (B) have characteristic long ears (photo courtesy of NPS). The range of this species in Wyoming (C) includes Fort Laramie NHS, indicated by the white arrow (adapted from Abernethy et al. 2015).

During the winter, long-eared Myotis tend to hibernate in caves (WGFD 2010). This species is a Tier II SGCN in Wyoming and is vulnerable to a variety of anthropogenic activities.

Indicator: Little Brown Myotis

Little brown myotis (*Myotis lucifugus*) have a broad distribution throughout North America, extending into northern Alaska (Figure 4.9.8). While this species uses human structures extensively for roosting, it is still affected by anthropogenic activities (WGFD 2010). Additionally, the little brown myotis is susceptible to WNS and has experienced population declines in the northeastern US because of the disease (Arroyo-Cabrales and Álvarez-Castañeda 2008b). The little brown myotis is currently being petitioned for listing under the Endangered Species Act and is a Tier II SGCN in Wyoming. This species roosts in wooded areas near open water (Arroyo-Cabrales and Álvarez-Castañeda 2008b, WGFD 2010).

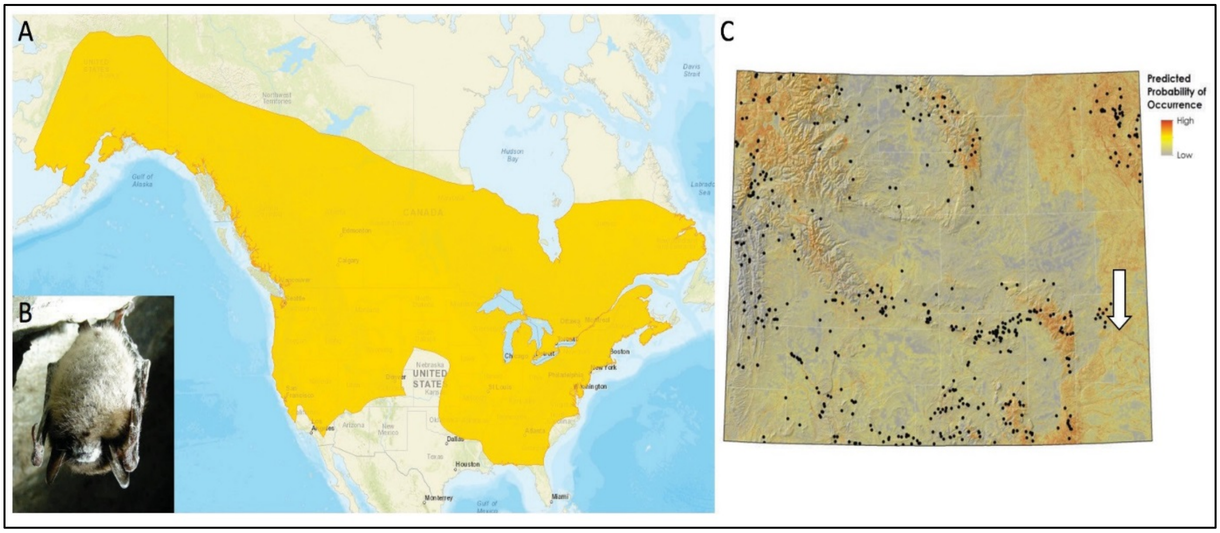

Figure 4.9.8. Distribution and probability of occurrence for the little brown myotis. The little brown myotis is (A) distributed throughout North America (IUCN 2016) and (B) is susceptible to white nose syndrome (photo by Marvin Moriarity 2009, courtesy of USFWS). The range of this in Wyoming (C) includes Fort Laramie NHS, indicated by the white arrow (adapted from Abernethy et al. 2015).

Indicator: Fringed Myotis

Fringed myotis (*Myotis thysanodes*) occur in western North America, from British Columbia through southern Mexico (Figure 4.9.9). This species inhabits a variety of dry conifer and shrubland environments, and uses diverse roosts from rock crevices and tree cavities to buildings and mines during the summer (Arroyo-Cabrales and de Grammont 2008, WGFD 2010).

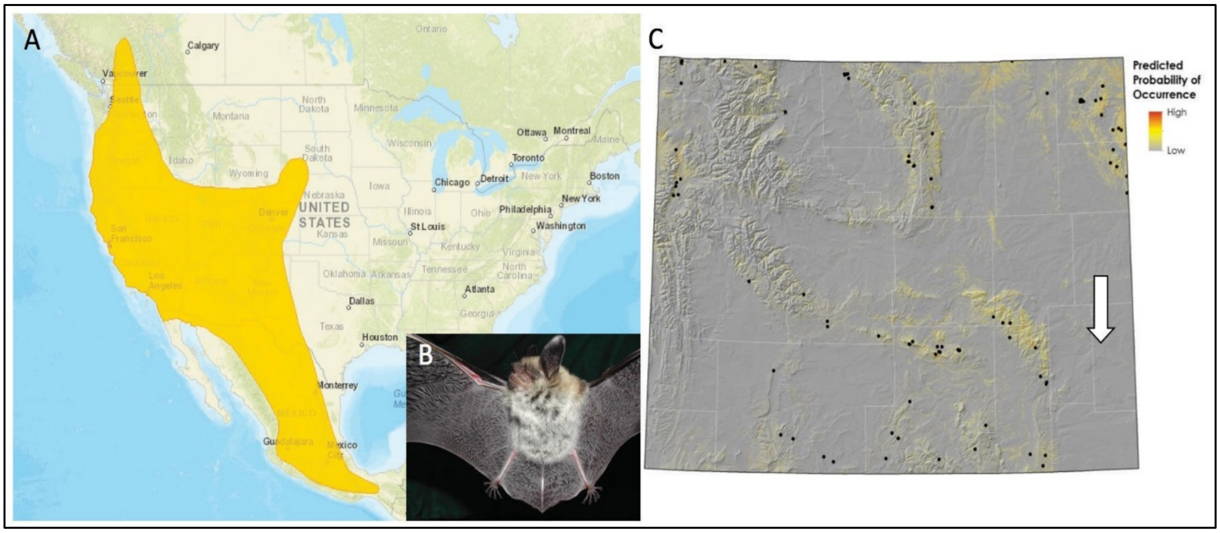

Figure 4.9.9. Distribution and probability of occurrence for the fringed myotis. The fringed myotis is (A) distributed throughout North America (IUCN 2016), is (B) of medium size, and has long ears (photo courtesy of USGS). The range of this species in Wyoming (C) includes Fort Laramie NHS, indicated by the white arrow (adapted from Abernethy et al. 2015).

The fringed myotis is a Tier II SGCN in Wyoming and is uncommon in the state (Abernethy et al. 2015).

Indicator: Long-legged Myotis

Long-legged myotis (*Myotis volans*) have a broad range through western North America (Figure 4.9.10) and frequently occur in large colonies of 2,000–5,000 individuals (Arroyo-Cabrales and Álvarez-Castañeda 2008c). This species inhabits forested environments and roosts in crevices during summer days, while typically hibernating in caves during the winter (Arroyo-Cabrales and Álvarez-Castañeda 2008c, WGFD 2010). The long-legged myotis is common in Wyoming (Abernethy et al. 2015), where it is a Tier II SGCN.

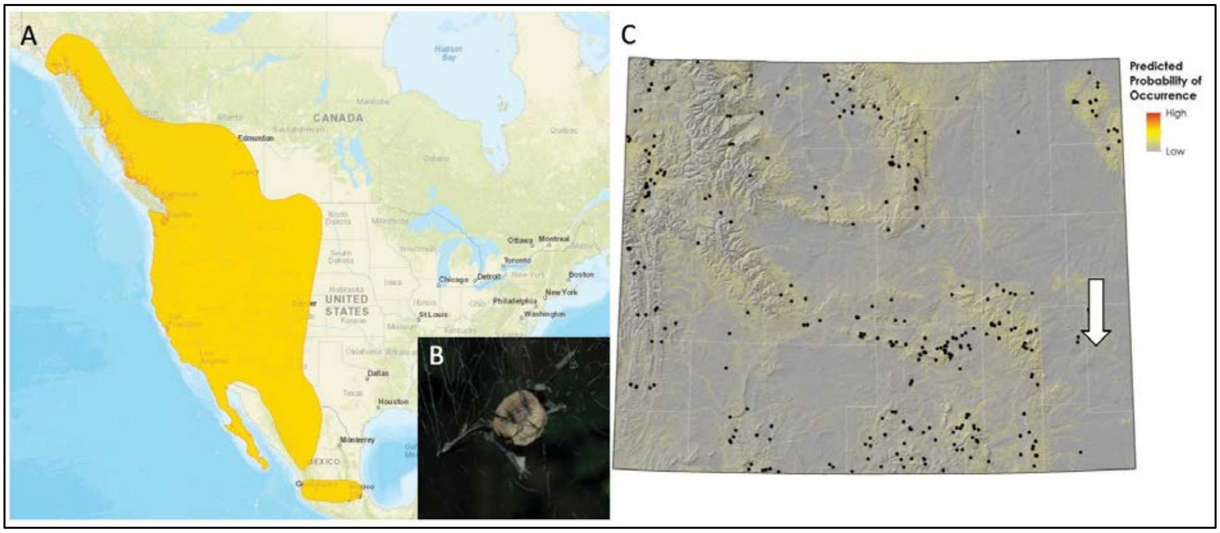

Figure 4.9.10. Distribution and probability of occurrence for the long-legged myotis. The long-legged myotis is (A) distributed throughout North America (IUCN 2016) and (B) forages for a short period of time each night (photo courtesy by Dan Neubaum of USGS). The range of this species in Wyoming (C) includes Fort Laramie NHS, indicated by the white arrow (adapted from Abernethy et al. 2015).

Indicator: Tri-colored Bat

Tri-colored bats (*Perimyotis [Pipistrellus] subflavus subflavus*) typically occur throughout eastern North American (Figure 4.9.11) and have only recently been considered as a possible resident species in Wyoming (I. Abernethy, personal communication, 26 August 2016). This species roosts in foliage of trees, in rock crevices, and in buildings and caves; they are usually found near water and in forest edges or openings (Arroyo-Cabrales et al. 2008b).

Figure 4.9.11. Distribution for the tri-colored bat. The tri-colored bat is (A) distributed throughout North America (IUCN 2016) and (B) is a potential resident of Wyoming (photo courtesy of USFWS).

Measure of All Indicator Bat Species: Population Growth Rate (λ)

One basic way to measure the health of a species is to monitor how the number of individuals changes 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 bats, a group that reproduces annually and typically have few young (Racey and Entwistle 2000), should be calculated over discrete time intervals to include new offspring. When λ=1, the population is stable, with no increases or decreases per year. If λ=1.1, the population has experienced a 10% increase per year, and if λ=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. A relatively stable number of individuals (λ=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 4.9.2).

Table 4.9.2. Bat condition categories for growth rate (λ).

Resource condition		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 increase with additional years of survey data.

Measure of All Indication Bat 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). For any bat species listed under the ESA, we gave that indicator the condition *Warrants Significant Concern*. To receive an ESA listing, species must be considered in a petition process. For any species currently being considered through a listing petition, we gave the condition *Warrants Moderate Concern*. In Wyoming, the State Wildlife Action Plan (WGFD 2010) designates Species of Greatest Conservation Need (SGCN) as high priority for conservation focus. The USDA Forest Service and Bureau of Land Management also maintain sensitive species lists (USDA Forest Service 2015, BLM 2015). For species with an SGCN or sensitive species status, we gave the condition as *Warrants Moderate Concern*. Species without conservation priority status received the condition, *Resource in Good Condition* (Table 4.9.3).

Table 4.9.3. Bat condition categories for level of conservation concern.

Resource condition		Conservation priority or protection
Warrants significant concern		Listing under ESA
Warrants moderate concern		Considered for listing under ESA; State or regional conservation priority
Resource in good condition		No listing, listing consideration, or special conservation status

<u>Environmental Characteristics</u>

Indicator: Exposure to White-nose Syndrome

White-nose syndrome (WNS) is an emerging disease caused by a fungus, which has resulted in massive population decline of bats in North America since 2006 (USFWS 2011). The fungus, *Geomyces destructans*, is native to Europe and was probably accidentally introduced to North America (Cryan et al. 2013); while the disease has been confirmed in several bat species in Europe, no evidence exists for massive mortality events there (Foley et al. 2011).

Hibernating bats are more susceptible to infection than migratory bats, though the specific environmental factors that best determine susceptibility are not well understood (USFWS 2011). Infected individuals exhibit white fungus around the muzzle, wings, and ears, lending the disease its name (Figure 4.9.8B). Mortality occurs when infected bats are more active during winter, depleting fat stores quickly.

Millions of bats have been lost due to WNS (White-Nose Syndrome 2016), putting once-common species at risk. If WNS were to infect bats in Wyoming, the consequent loss could be substantial. At the time of this report, the closest confirmed infection to Wyoming was in Iowa and the closest suspected infection was in eastern Nebraska (Figure 4.9.12).

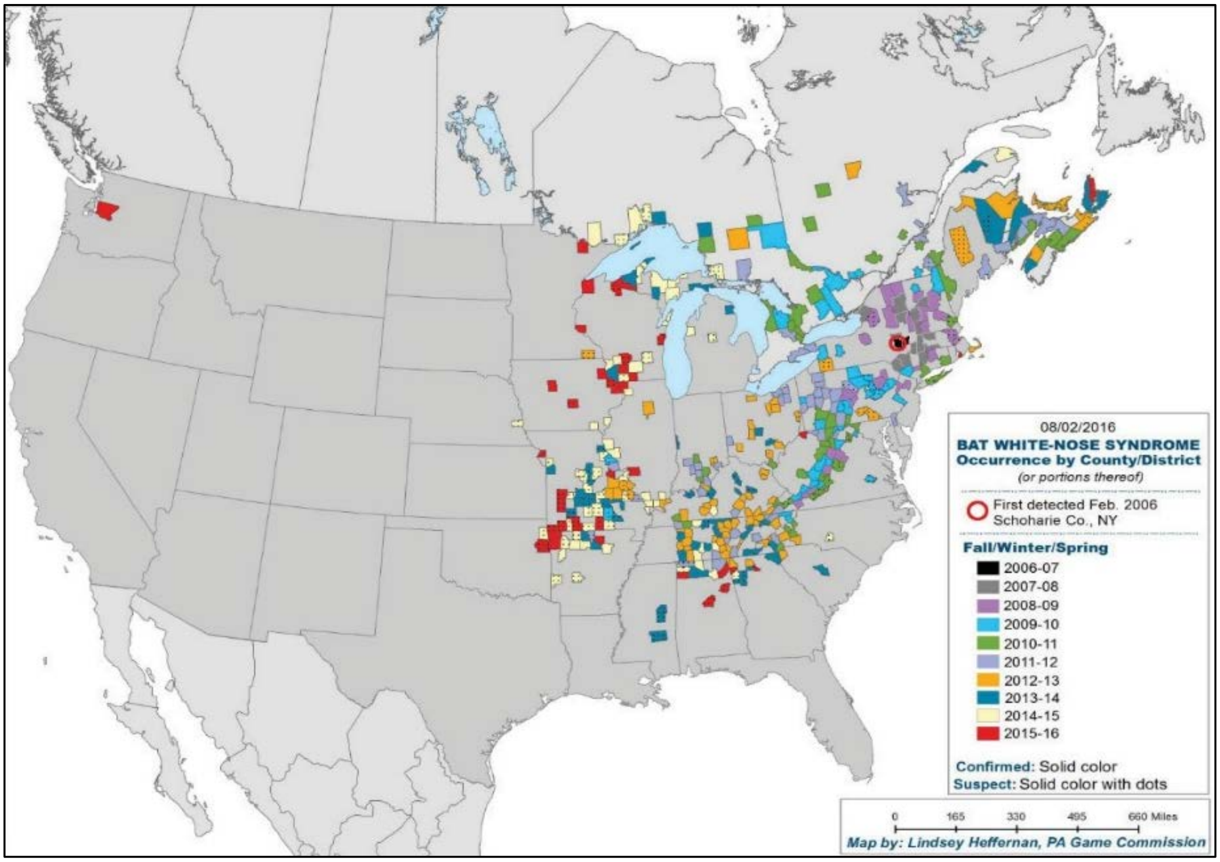

Figure 4.9.12. Confirmed and suspected infections of white-nose syndrome, color-coded by year from first detection in 2006 through August 2, 2016 (White-Nose Syndrome 2016).

Measure of Exposure to White-nose Syndrome: Presence, Absence, or Proximity

The Wyoming Bat Working Group wrote a strategic plan for managing WNS and developed a three-stage alert system (Abel and Grenier 2012). We have used their criteria to create condition categories for this assessment (Figure 4.9.13). If WNS detection was > 250 miles (> 400 kilometers) from the Wyoming border, we gave the condition, *Resource in Good Condition*. If WNS was < 250 miles from the state border but not yet in Wyoming, we assigned the condition, *Warrants Moderate Concern*. If WNS was detected within the state, we gave the condition, *Warrants Significant Concern* (Table 4.9.4).

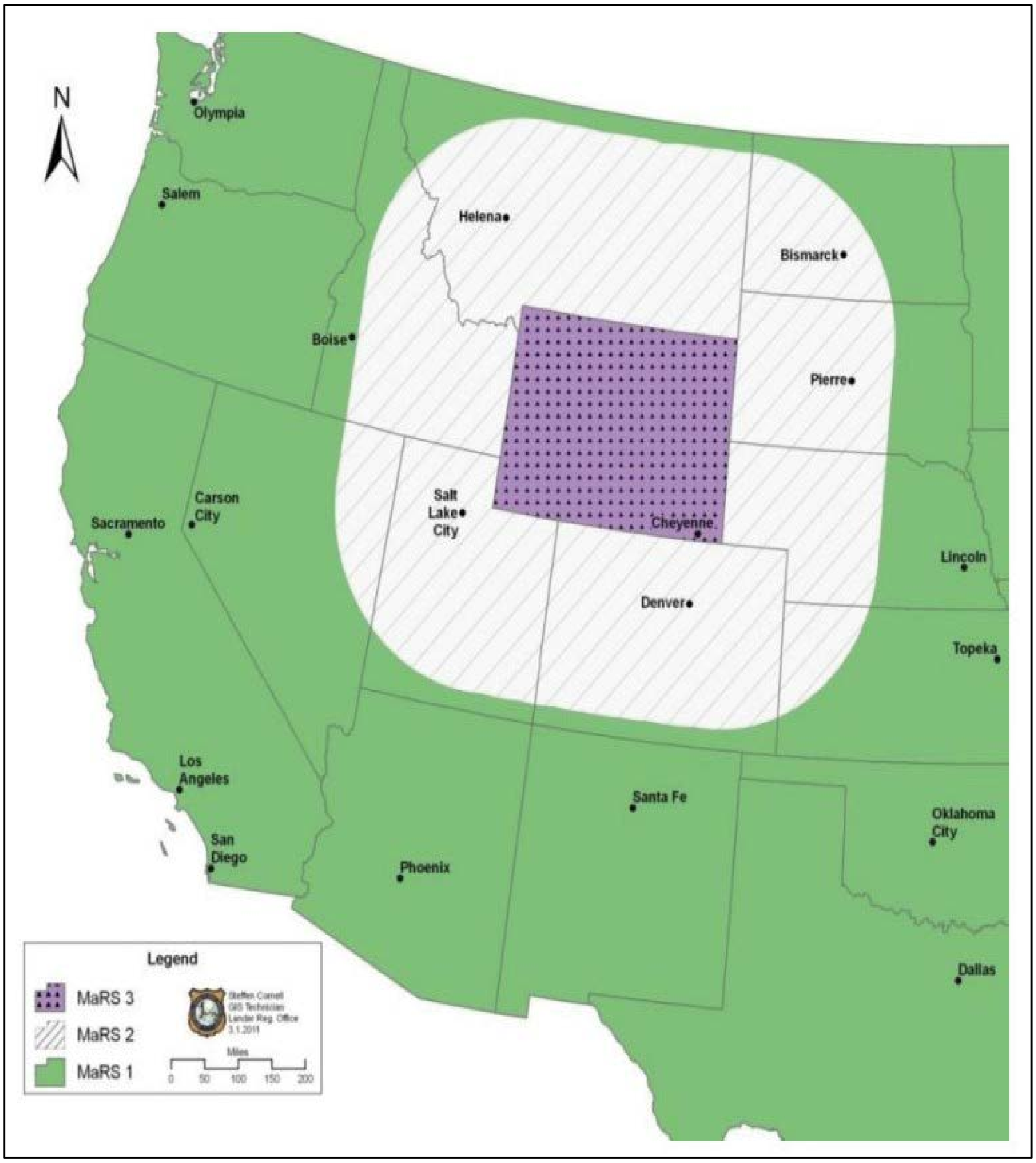

Figure 4.9.13. Buffer zones for WNS detection and management response stages (Abel and Grenier 2012) used as condition categories in this assessment.

Table 4.9.4. Bat condition categories for exposure to white-nose syndrome (WNS).

Resource condition		Distance of WNS from Wyoming
Warrants significant concern		Within Wyoming border
Warrants moderate concern		< 250 miles (< 400 kilometers) but not within Wyoming border
Resource in good condition		> 250 miles (> 400 kilometers)

Data Collection and Sources

Data Management and Availability

For this assessment we used data collected by Licht (2016) at Fort Laramie NHS in 2015, the Species of Greatest Conservation Need list in the State Wildlife Action Plan for Wyoming (WGFD 2010), sensitive species lists for Region 2 of the Forest Service (USDA Forest Service 2015) and for Wyoming by BLM (BLM 2015), and expert opinion.

Quantifying Bat Condition, Confidence, and Trend

Indicator Condition

To quantify bat 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. 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* (Table 4.9.5).

Table 4.9.5. Summary of bat indicators and measures.

Indicator	Measure	Condition	Confidence	Trend	Condition rationale
Townsend's big-eared bat	Population growth rate (λ)	Warrants moderate concern	High	Not available	Townsend's big-eared bat was listed as a Tier I SGCN and as a sensitive species by both BLM and the Forest Service.
	Level of conservation concern				

Table 4.9.5 (continued). Summary of bat indicators and measures.

Indicator	Measure	Condition	Confidence	Trend	Condition rationale
Big brown bat	Population growth rate (λ) Level of conservation concern	Warrants moderate concern	Medium	Not available	The big brown bat was listed as a Tier II SGCN.
Eastern red bat	Population growth rate (λ) Level of conservation concern	Warrants moderate concern	Medium	Not available	The eastern red bat was listed as a Tier II SGCN.
Hoary bat	Population growth rate (λ) Level of conservation concern	Warrants moderate concern	Medium	Not available	The hoary bat was listed as a sensitive species in the Rocky Mountain Region by the Forest Service
Silver-haired bat	Population growth rate (λ) Level of conservation concern	Resource in good condition	Medium	Not available	The silver-haired bat was not a listed species of concern.
Small-footed myotis	Population growth rate (λ) Level of conservation concern	Warrants moderate concern	Medium	Not available	The small-footed myotis was listed as a Tier II SGCN.
Long-eared myotis	Population growth rate (λ) Level of conservation concern	Warrants moderate concern	High	Not available	The long-eared myotis was listed as a Tier II SGCN and as a sensitive species by the BLM.
Little brown myotis	Population growth rate (λ) Level of conservation concern	Warrants moderate concern	High	Not available	The little brown myotis was listed as a Tier II SGCN and is currently being petitioned for ESA listing.
Fringed myotis	Population growth rate (λ) Level of conservation concern	Warrants moderate concern	High	Not available	Fringed myotis was listed as a Tier II SGCN and as a sensitive species by both BLM and the Forest Service.
Long-legged myotis	Population growth rate (λ) Level of conservation concern	Warrants moderate concern	Medium	Not available	The long-legged myotis was listed as a Tier II SGCN.
Tri-colored bat	Population growth rate (λ) Level of conservation concern	Warrants moderate concern	Medium	Not available	The tri-colored bat was being petitioned for ESA listing at the time of this assessment

Table 4.9.5 (continued). Summary of bat indicators and measures.

Indicator	Measure	Condition	Confidence	Trend	Condition rationale
White-nose syndrome	Population growth rate (λ)	Resource in good condition	High	Unchanging	At the time of this assessment, white-nose syndrome was >250 miles from the Wyoming border, with the nearest suspected occurrence over 400 miles (650 kilometers) away in eastern Nebraska and the nearest confirmed occurrences in Iowa and Missouri
	Level of conservation concern				

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, if more than one source indicated a similar condition we assigned a *High* confidence. 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 bat species, we required at least three years of abundance data for that species. White-nose syndrome can spread quickly and is likely to cause precipitous population declines if bats become infected (USFWS 2011); two years of mortality and infection data should be sufficient to calculate a conservative trend. 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 Bat Condition, Trend, and Confidence

We used the general approach for combining indicator conditions, trends, and confidence described in Chapter 3 (Methods 3.2.2) to calculate overall bat condition, trend, and confidence (Table 4.9.5).

4.9.4. Bat Conditions, Confidence, and Trends

Bat recordings at stationary points occurred over 20 recording nights at four recording stations at Fort Laramie NHS. The average number of bat detections per night per station was 1,351 (Licht 2015), which was higher than in any other park in the Northern Great Plains Network. One of the recording points included the bat house, a constructed roost at the park, and accounted for the majority of bat recordings (Licht 2015). These data indicated that Fort Laramie NHS has a diverse bat community, but abundance estimates were unavailable. We, therefore, used these data to confirm presence at the site and deferred to listing status to generate a condition for each indicator species. If an index of abundance (for example, number of detections of bat species X per time unit Y) were formalized, managers could apply the index to these data as a baseline to detect changes in relative abundance over time and compare the two monitoring methods (stationary points and mobiles surveys).

Townsend's Big-eared Bat (*Corynorhinus townsendii pallescens*)

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

Condition

Townsend's big-eared bat was listed as a Tier I SGCN and as a sensitive species by both BLM and the Forest Service. Condition of this indicator species was *Warrants Moderate Concern*.

Confidence

Population data were not available for Townsend's big-eared bat, but at the time of this assessment the bat appeared on multiple sensitive species lists. Confidence was *High*.

Trend

Trend was *Not Available*.

Big Brown Bat (*Eptesicus fuscus*)

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

Condition

The big brown bat was listed as a Tier II SGCN. Condition of this indicator species was *Warrants Moderate Concern*.

Confidence

Population data were not available for big brown bat, but at the time of this assessment the species appeared on the Wyoming SGCN list. Survey data from Fort Laramie NHS in 2015 confirmed that this species was present. Confidence was *Medium*.

Trend

Trend was *Not Available*.

Eastern Red Bat (*Lasiurus borealis*)

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

Condition

The eastern red bat was listed as a Tier II SGCN. Condition of this indicator species was *Warrants Moderate Concern*.

Confidence

Population data were not available for this bat, but at the time of this assessment the species appeared on the Wyoming SGCN list. Confidence was *Medium*.

Trend

Trend was *Not Available*.

Hoary Bat (*Lasiurus cinereus cinereis*)

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

Condition

The hoary bat was listed as a sensitive species in the Rocky Mountain Region by the Forest Service. Condition of this indicator species was *Warrants Moderate Concern*.

Confidence

Population data were not available for this bat, but at the time of this assessment the species appeared on one sensitive species list. Survey data from Fort Laramie NHS in 2015 confirmed that this species was present. Confidence was *Medium*.

Trend

Trend was *Not Available*.

Silver-haired Bat (*Lasionycteris noctivagans*)

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

Condition

The silver-haired bat was not a listed species of concern. Condition of this indicator species was *Resource in Good Condition*.

Confidence

Population data were not available for this bat, but at the time of this assessment the silver-haired bat did not appear on sensitive species lists. Additionally, survey data from Fort Laramie NHS in 2015 confirmed that this species was present. Confidence was *Medium*.

Trend

Trend was *Not Available*.

Small-footed Myotis (*Myotis ciliolabrum*)

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

Condition

The small-footed myotis was listed as a Tier II SGCN. Condition of this indicator species was *Warrants Moderate Concern*.

Confidence

Population data were not available for this bat, but at the time of this assessment the species appeared on one sensitive species list. Confidence was *Medium*.

Trend

Trend was *Not Available*.

Long-eared Myotis (*Myotis evotis*)

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

Condition

The long-eared myotis was listed as a Tier II SGCN and as a sensitive species by the BLM. Condition of this indicator species was *Warrants Moderate Concern*.

Confidence

Population data were not available for this bat, but at the time of this assessment the bat appeared on multiple sensitive species lists. Confidence was *High*.

Trend

Trend was *Not Available*.

Little Brown Myotis (*Myotis lucifugus*)

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

Condition

The little brown myotis was listed as a Tier II SGCN and is currently being petitioned for ESA listing. Condition of this indicator species was *Warrants Moderate Concern*.

Confidence

Population data were not available for this bat, but at the time of this assessment the little brown myotis appeared on multiple lists. Confidence was *High*.

Trend

Trend was *Not Available*.

Fringed Myotis (*Myotis thysanodes*)

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

Condition

Fringed myotis was listed as a Tier II SGCN and as a sensitive species by both BLM and the Forest Service. Condition of this indicator species was *Warrants Moderate Concern*.

Confidence

Population data were not available for fringes myotis, but at the time of this assessment the bat appeared on multiple sensitive species lists. Confidence was *High*.

Trend

Trend was Not Available.

<u>Long-legged Myotis (*Myotis volans*)</u>

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

Condition

The long-legged myotis was listed as a Tier II SGCN. Condition of this indicator species was *Warrants Moderate Concern*.

Confidence

Population data were not available for this bat, but at the time of this assessment the long-legged myotis appeared on one sensitive species list. Confidence was *Medium*.

Trend

Trend was *Not Available*.

<u>Tri-colored Bat (*Perimyotis subflavus subflavus*)</u>

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

Condition

The tri-colored bat was being petitioned for ESA listing at the time of this assessment. Condition of this indicator species was *Warrants Moderate Concern*.

Confidence

Population data were not available for the tri-colored bat, but at the time of this assessment the species was under petition for ESA listing. Confidence was *Medium*.

Trend

Trend was *Not Available*.

White-nose Syndrome

Condition: Resource in Good Condition Confidence: High Trend: Unchanging

Condition

At the time of this assessment, white-nose syndrome was > 250 miles from the Wyoming border, with the nearest suspected occurrence over 400 miles (650 kilometers) away in eastern Nebraska and the nearest confirmed occurrences in Iowa and Missouri (Figure 4.9.12). Because these occurrences were > 250 miles from the Wyoming border, the condition for WNS at Fort Laramie NHS was *Resource in Good Condition*.

Confidence

White nose syndrome is an emerging disease of national concern and is monitored closely by government and non-government agencies (e.g., USFWS 2011, Abel and Grenier 2012, White-Nose Syndrome 2016). Beginning in 2010, White-Nose Syndrome.org (2016) has published WNS occurrence maps that include the new detections as they are reported each summer. In Wyoming, bat surveys have included the goal of documenting any occurrence of WNS; no occurrences were detected (Abernethy et al. 2015). Confidence was *High*.

Trend

White-nose syndrome was not present at Fort Laramie NHS at the time of this assessment, nor had it been present previously detected in Wyoming. Trend was *Unchanging*.

Bat Overall Condition

Table 4.9.6. Bat overall condition.

Indicators	Measures	Condition
Townsend's Big-eared Bat (*Corynorhinus townsendii pallescens*)	• Population growth rate • Level of conservation concern	
Big Brown Bat (*Eptesicus fuscus*)	• Population growth rate • Level of conservation concern	

Table 4.9.6 (continued). Bat overall condition.

Indicators	Measures	Condition
Eastern Red Bat (*Lasiurus borealis*)	• Population growth rate • Level of conservation concern	
Hoary Bat (*Lasiurus cinereus cinereis*)	• Population growth rate • Level of conservation concern	
Silver-haired Bat (*Lasionycteris noctivagans*)	• Population growth rate • Level of conservation concern	
Small-footed Myotis (*Myotis ciliolabrum*)	• Population growth rate • Level of conservation concern	
Long-eared Myotis (*Myotis evotis*)	• Population growth rate • Level of conservation concern	
Little Brown Myotis (*Myotis lucifugus*)	• Population growth rate • Level of conservation concern	
Fringed Myotis (*Myotis thysanodes*)	• Population growth rate • Level of conservation concern	
Long-legged Myotis (*Myotis volans*)	• Population growth rate • Level of conservation concern	
Tri-colored Bat (*Perimyotis subflavus subflavus*)	• Population growth rate • Level of conservation concern	
Exposure to white-nose syndrome	• Presence, absence, or proximity	
Overall condition for all indicators and measures		

Condition

Overall bat condition was determined by the average of the indicator conditions. We summarized the condition, confidence, and trend for each indicator, and assigned condition points. The total score for overall bat condition was 58 points, which *Warrants Moderate Concern*.

Confidence

The score for overall confidence was 71 points, which met the criteria for a *High* level of confidence in overall bat condition.

Trend

Trend was unchanging for WNS, but unavailable for the other indicators. Overall trend for bat condition was *Not Available*.

4.9.5. Stressors

Fort Laramie NHS has a relatively large number of bat species and bat occurrences (Licht 2016), but a number of stressors threaten the health of these bats and Wyoming bats in general. The State Wildlife Action Plan for Wyoming (WGFD 2010) identifies key these threats to Wyoming bats as wind energy development, insect control programs, some recreational activities such as rock climbing (and spelunking where caves are present), and mine closures that neglect to mitigate for potential use by bats. While insect control programs may be the only of these identified threats that could be managed on site at Fort Laramie NHS, land use practices in the surrounding area could affect bats within the park unit.

For most bats, summer day roosts and winter hibernacula are likely to be the most limiting factors for population size (I. Abernethy, personal communication, 24 August 2016). Recovery criteria for bat species listed under the Endangered Species Act have focused on the protection of these habitat features, but designating critical habitat for bats can increase vandalism and these criteria are, therefore, not always regulated (e.g., 50 CFR Part 17 2016). This change in regulation may increase the importance of protecting bat habitat in protected areas.

White-nose syndrome is one of the greatest threats to bats. Though the disease has not yet appeared in Wyoming, or within 250 miles of the state border, it may appear in the next few years. Methods to prevent infection and spread of WNS have not yet been developed, though humans should take great care to reduce the possibility of spreading WNS (White-Nose Syndrome 2016).

4.9.6. Data Gaps

To detect a change in local bat populations, the most practical approach would be to derive an abundance index from acoustic monitoring (I. Abernethy, personal communication, 26 August 2016). For example, a bat abundance index could be the number of recordings from species X per unit time; repeated annually, this approach could reveal relative changes in bat numbers.

Environmental testing for WNS, including soil sampling and hibernacula testing, could give some advance notice of the presence of the disease (I. Abernethy, personal communication, 24 August 2016).

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4.10. Invertebrate Pollinators

Red admiral butterflies are present at Fort Laramie NHS (Photo: B. Kohl 2009).

4.10.1. 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.

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 part of research programs at several national parks and pollinator education programs were growing at the time of this assessment (NPS 2016).

<u>Regional Context</u>

Wyoming invertebrate pollinators include native insects and honey bees that vary in diversity and abundance across the landscape (DePaolo et al. 2014). The most recent invertebrate survey available for Fort Laramie NHS confirmed that the park is home to a total of 16 species, though the authors suggest that the true number of species present is likely to be much higher (Opler and Garhart 2004). Pearl crescent (*Phyciodes tharos*) were found within the park (Figure 4.10.1A), as were red admirals (*Vanessa atalanta rubria*) (Figure 4.10.1B) and melissa blue butterflies (*Plebejus melissa*) (Opler and Garhart 2004, Figure 4.10.1C).

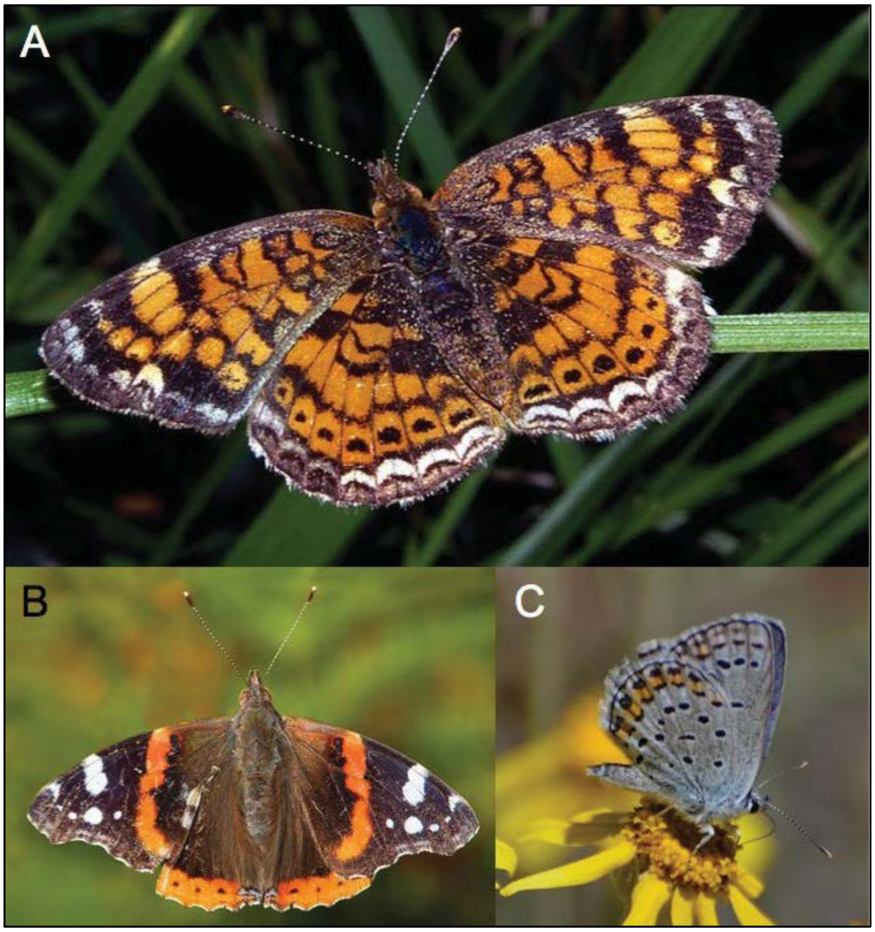

Figure 4.10.1. Butterfly species present at Fort Laramie NHS (Opler and Garhart 2004). Species include A) pearl crescent butterfly (*Phyciodes tharos*), B) red admirals (*Vanessa atalanta rubria*), C) and melissa blue butterflies (*Plebejus melissa*) (Photos: K.D. Harrelson (2007), B. Kohl (2009), and A. Reago and C. McClarren (2014), respectively).

While bumble bees (*Bombus* sp.) and other invertebrate pollinators are likely present in Fort Laramie NHS (Koch et al. 2012), local census data are lacking for the park. In Wyoming, wind farms present a growing challenge for invertebrate pollinators as insect kills on turbine blades can be substantial (DePaolo et al. 2014). Some plants of concern in the region around Fort Laramie NHS, such as alpine feverfew (*Parthenium alpinum*), likely rely on pollinators other than butterflies or bees (Heidel and Handley 2004).

4.10.2. 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 U.S.C. § 1531 et seq. 1973), if recovery plans have been completed. At the time of this assessment no invertebrate pollinator species in Wyoming were listed under ESA, several bees and butterflies were under review for listing (USFWS 2016).

4.10.3. Methods

Indicators and Measures

We assessed invertebrate pollinator condition at Fort Laramie NHS 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 for Invertebrate Conservation Red Lists (Xerces Society 2016a, 2016b), indicate a level of concern for the species as well. 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 Fort Laramie NHS. 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 (Opler and Garhart 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 Fort Laramie NHS.

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 4.10.1). In the absence of adequate quantitative data, we assigned condition based on qualitative information, expert opinion, and consultation with NPS scientists.

Table 4.10.1. Summary of invertebrate pollinators' indicators and measures.

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 presence, but species of concern and species being considered for ESA listing could be present.

4.10.4. Invertebrate Pollinator Conditions, Confidence, and Trends

Few data on pollinators were available for Fort Laramie NHS, though we were able to reference a small butterfly census survey (Opler and Garhart 2004). Xerces Society Red Lists identified a number of species of concern in Wyoming, but at the time of this assessment none of these species had been identified as present in Fort Laramie NHS.

Diversity

Condition: Not Available Confidence: Low Trend: Not Available

Condition

A butterfly species lists existed for Fort Laramie NHS (Opler and Garhart 2004), but no such list exists for other invertebrate pollinators. The butterfly survey involved a census of species present throughout the park, plus a second site. Sampling was conducted on three occasions, and the only spring survey was too windy to yield reliable results (Opler and Garhart 2004).

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 Fort Laramie NHS, 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 Fort Laramie NHS. 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

Several butterflies of conservation concern may be present in Fort Laramie NHS, but had not been confirmed as present at the time of this assessment. These species include regal fritillary (*Speyeria idalia*), arogos skipper (*Atrytone arogos*), and ottoe skipper (*Hesperia ottoe*), all of which the Xerces Society deems to be vulnerable species (Xerces Society 2016b). A bumble bee species of conservation concern, the western bumble bee (*Bombus occidentalis*), was under petition for ESA listing and likely present Fort Laramie NHS (Xerces Society 2016a), but had not been confirmed as present at the time of this assessment.

Several invertebrate pollinators of conservation concern were likely present at Fort Laramie NHS. Condition was *Warrants Moderate Concern*.

Confidence

Few data existed for invertebrate pollinators at Fort Laramie NHS, and were collected for only one type of invertebrate pollinator. Confidence was *Low*.

Trend

Trend was *Not Available*.

Invertebrate Pollinators Overall Condition

Table 4.10.2. Invertebrate pollinators overall condition.

Indicators	Measures	Condition
Diversity	Shannon index	
Abundance	Mean visitation rate Mean density in traps	
Vulnerable species	Level of conservation concern	

Table 4.10.2 (continued). Invertebrate pollinators overall condition.

Indicators	Measures	Condition
Overall condition for all indicators and measures		

Condition

Condition was unavailable for the diversity and abundance indicators due to a lack of reference standards and data. Several species of conservation concern were likely to be present. Condition was *Warrants Moderate Concern*.

Confidence

Few data existed for invertebrate pollinators at Fort Laramie NHS, and were collected for only one type of invertebrate pollinator. Confidence was *Low*.

Trend

Trend was *Not Available*.

4.10.5. 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 Wyoming, insecticide use, land conversion, and changes in climate could contribute to these declines.

Wind energy could also negatively affect pollinators (DePaolo et al. 2014) through direct kills on turbine blades and through land conversion. 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. Fort Laramie NHS 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, may be a challenge to consider in the future.

4.10.6. Data Gaps

Butterfly data collected over 10 years prior to this assessment (Opler and Garhart 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 Fort Laramie NHS, 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 section 4.5 Water Quality). Until such metrics are developed, pollinator researchers and managers may find some agreement about expected levels of diversity in various ecosystem types.

Acknowledgments
Many thanks to Dr. Lusha Tronstad at Wyoming Natural Diversity Database for providing guidance on how to approach the assessment of invertebrate pollinators at Fort Laramie NHS.

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Chapter 5. Discussion of Natural Resource Condition Assessment Findings and Considerations for Park Planning

5.1. Introduction

This chapter summarizes (Table 5.1) natural resource conditions, potential threats and stressors to those resources, scientific needs and data gaps, and management issues for Fort Laramie National Historic Site. The summaries and recommendations presented are the result of discussions among park managers, NPS natural resources staff, 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 Fort Laramie NHS that would enable managers to maintain or improve resource conditions.

Natural resource management priorities are considered alongside cultural resources and park infrastructure (Photo: Chris Light, Wikimedia Commons 2007).

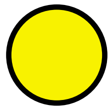
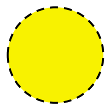
Table 5.1.1. Summary of natural resources conditions, confidence, trends, and rationale for resource condition.

Priority resource	Condition, confidence, and trend	Rationale for 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 indicated good condition, as did a 73.9% natural land cover and 7.52% developed land cover.
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 indicated good condition and anthropogenic light ratio was of moderate concern. Night sky conditions have deteriorated since the most recent monitoring within the park. Construction of rail and truck oil terminal facilities, completed in 2014 and 2015, have added light pollution to the night sky. Overall condition was of moderate concern.

Table 5.1 (continued). Summary of natural resources conditions, confidence, trends, and rationale for resource condition.

Priority resource	Condition, confidence, and trend	Rationale for 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 of significant concern. Stressors included 3-4 coal/oil trains per hour, the heavy truck traffic on surrounding roads, truck-to-pipeline transfer facilities, and air traffic overhead.
Air Quality		Fort Laramie 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 north of the park and smoke from increasingly frequent fires may be affecting air quality to some extent and are expected to increase in the future.
Surface water quality		We assessed water quality using the most recent data available for core and biological indicators. Core indicators were a mix of good and moderate condition, invertebrate indicators were of moderate condition, and fecal bacteria were in good condition. Overall condition was good.
Geology		Major geologic resources in Fort Laramie NHS are sedimentary deposits: the unconsolidated river muds, sands and gravels of the Laramie and North Platte Rivers. We assessed condition of sediment transport using a historical comparison of events most likely to move sediment within the park. Seasonal flooding is a natural process, and recent events in the park were within the range of natural variation; condition was good. On the other hand, flooding can damage park cultural resources and infrastructure, so management of this resource will likely require a balance between natural variation and other park goals.
Vegetation		A complete vegetation assessment was completed for Fort Laramie NHS in the course of this NRCA and we based our assessment entirely on those results. Several measures of upland plant community, exotic plant detection, and riparian forest 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.

Table 5.1 (continued). Summary of natural resources conditions, confidence, trends, and rationale for resource condition.

Priority resource	Condition, confidence, and trend	Rationale for overall condition
Bats		Many bats are at risk and sensitive across large portions of their range; we assessed bat condition by looking at condition of 11 individual bat species and the potential presence of an infectious fungus. Overall bat condition was of moderate concern, although others are at a higher level of concern.
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

Fort Laramie NHS is well known as an important historical and cultural landmark, and less identified with its abundant natural resources. Natural resources in the park 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, leadership at Fort Laramie NHS would like to draw more visitor attention to the natural resources at the park. The riparian areas, in particular, are habitat for birds and bats and the two major rivers that border the park support prey for many of these species. Highlighting these aspects of the park and other natural resources could attract a new visitor demographic to Fort Laramie NHS.

Second, administrative and natural resource leadership at Fort Laramie NHS expressed concern that the park unit and NPS, in general, did not have the resources to gather the kind of scientific data that is required for a thorough site-specific assessment (T. Baker and M. Evans, personal communication 28 September 2016). Due to this lack of site-specific data, we relied on regional and remotely sensed data to assess many of the natural resources. While data collected at broad scales can be useful for discerning general trends, Fort Laramie NHS would have a better understanding of the natural resources if certain data were collected within the park unit.

Additionally, as a small unit, park staff discussed the vulnerability of Fort Laramie NHS 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.

Another common challenge at Fort Laramie NHS is the need to manage both cultural and natural resources that sometimes have conflicting management needs. In particular, flooding of the Laramie

River is a natural process but large floods have caused damage to archaeological resources and to bridges in the park and could damage buildings in the future. Therefore, mitigating flood damage is imperative for Fort Laramie NHS. Likewise, bats, an important biological resource in the park, affect air quality and visitor experience in historic buildings. While discussing particular management strategies to address these conflicts is beyond the scope of this assessment, park managers must constantly balance management of these competing resources.

5.4. Resource Summaries and Management Issues

In addition to the general data gaps and management issues discussed above, we present resource-specific details on management concerns. For each resource, we present a brief description of the context at Fort Laramie NHS, summarize condition of the resource, and then describe data gaps and management issues.

5.4.1. Viewshed

At Fort Laramie NHS, the historic fort structures, cultural landscapes, Laramie and North Platte Rivers, and views of the prairies, ranch lands, and mountains all contribute to visitor experience. The landscapes in and around the park offer visitors opportunities to enjoy visual settings that guided American Indians, overland fur traders, and emigrants on the westward trails.

Viewshed Condition Summary

Viewshed condition depended on two indicators: scenic quality of view and land cover types within the viewshed. Three measures of scenic quality (landscape character integrity, vividness, and visual harmony) indicated good condition, as did a 73.9% natural land cover and 7.52% developed land cover. Viewshed was in *Good Condition*, confidence in condition was *High*, 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. Following this inventory, the park can develop a monitoring approach.

Potential future development around Fort Laramie NHS is a concern to park managers. Construction of wind turbines could affect viewshed, but is not currently an imminent threat. Very little land around the park is managed by federal agencies, so the park has limited official nexus to engage in planning processes.

5.4.2. Night Sky

Night skies helped to guide early settlers, fur trappers, and traders to eastern Wyoming and Fort Laramie, and park visitors still come to Fort Laramie NHS for stargazing experiences. The 2016 Centennial Night Sky Event at Fort Laramie NHS drew visitors for a guided tour to the stars and telescope observation of the sky. Since about 2006, star gazing events have been scheduled each summer at Fort Laramie NHS in July or early August on nights when the moon will not interfere with viewing deep sky objects.

Night Sky Condition Summary

The 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, and anthropogenic light ratio was of moderate concern. Since the most recent monitoring within Fort Laramie NHS, night sky conditions have deteriorated (T. Baker, personal communication, 28 September 2016). Construction of an oil train terminal was completed in 2014, a truck-to-pipeline facility in 2015, and continuous expansions of tank farms are creating new sources of light pollution. Overall condition was of moderate concern. Additional threats to dark skies included lighting at existing facilities in the area surrounding the park, such as the Guernsey oil tank farm and the Fort Laramie municipal water tower. Night sky condition *Warrants Moderate Concern*, confidence in condition was *Medium*, and trend was *Deteriorating* (Table 5.1).

Night Sky Gaps and Management Issues

Data used in this assessment included the most recent measurements available, but did not include recent contributions to light pollution. Collection of new on-site data is warranted, given the changes that have occurred around the park since the last monitoring effort.

Management issues for night sky are similar to those for viewshed; Fort Laramie NHS has limited official capacity to engage in external planning process, as well as few people to tackle a broad range of management issues. Knowing the sources of light that are or are likely to be of particular concern would help Fort Laramie NHS managers to engage in solution-oriented discussions with neighbors to minimize light intrusion.

5.4.3. Soundscape

Fort Laramie NHS is surrounded by agricultural operations and roads, and is located less than two kilometers (1.2 miles) west of the small town of Fort Laramie. Primary sources of non-natural sounds within the park include 3–4 coal/oil trains per hour, operations at the oil transfer facilities, automobile traffic, visitor conversations and associated acoustics, maintenance operations, agricultural activities, and air traffic passing overhead.

Soundscape Condition Summary

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 of significant concern, given the stressors identified above. Soundscape condition *Warrants Significant Concern*, confidence in condition was *High*, and trend was *Not Available* (Table 5.1).

Soundscape Gaps and Management Issues

Site-specific data were unavailable and the modeled data used in this assessment did not include fine-scale measurements of the various sources of noise in the park. Management issues for soundscape are the same as those for night sky and viewshed; Fort Laramie NHS has limited official capacity to engage in external planning processes, as well as few people to tackle a broad range of management issues.

5.4.4. Air Quality

Fort Laramie NHS is located in Goshen County where there were not enough monitoring data from 2014–2015 to assign a score, but adjacent Laramie County received the highest possible grade (A) for that time period. There is, however, significant heterogeneity in air quality within the region. During the same time period, Sublette County, which is 210 miles (350 kilometers) west of Goshen, received the lowest possible grade (F) due to ozone and particulate pollution. The disparity in these grades within Wyoming highlights the importance of identifying local air quality conditions.

Air Quality Condition Summary

Fort Laramie is a Class II airshed and is 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 and north by the of the park, particularly the potential Greater Crossbow Oil and Gas Development, and smoke from wildfires may be degrading air quality and could increase in the future. Air quality condition *Warrants Moderate Concern*, confidence in condition was *Medium*, and trend was *Not Available* (Table 5.1).

Air Quality Gaps and Management Issues

Some site-specific data were available, though most data were measured at locations outside of the park. Management issues for air quality are the same as those for the other resources affected by processes at a broad landscape context; Fort Laramie NHS has limited official capacity to engage in external planning processes, as well as few people to tackle a broad range of management issues. While an on-site air quality monitor would improve data resolution, maintaining additional air quality monitoring facilities would be a financial burden to the park.

5.4.5. Water Quality

Fort Laramie NHS is located in southeast Wyoming at the confluence of the Laramie and North Platte Rivers, which eventually flow east into the Missouri River. The Laramie River is a prominent natural feature that bisects the park unit and is an important resource for plants and wildlife in the region. The North Platte River that bounds Fort Laramie NHS on the east side is larger than the Laramie River, but the section of Laramie River that winds through the park unit is a higher 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 a mix of good and moderate condition, invertebrate indicators were of moderate condition, and fecal bacteria were in good condition. Overall water quality condition *Resource in Good Condition*, confidence in condition was *Medium*, and trend was *Not Available* (Table 5.1).

Water Quality Gaps and Management Issues

Fort Laramie NHS is on a rotation for USGS water quality sampling every three years. If resources were available, a continuous monitoring station within the park would be valuable, especially given the prominence of the rivers that pass through the park. Biological data collected in the park were very helpful in assigning water quality condition, and should be monitored in the future as well.

Upstream infrastructure and activities most likely to affect water quality in the Laramie River are grazing, hay production, and flow alteration from Grayrocks Reservoir and Wheatland Reservoir. Changes to land use or land management practices could have consequences in the future. 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.

Management issues for water quality are similar to those for the other resources affected by processes at a broad landscape context, though are focused on activities upstream of the park; Fort Laramie NHS has limited direct influence on these activities.

5.4.6. Geology

Surface and subsurface strata of the Great Plains physiographic province represent many different paleo environments spanning millions of years. While older rocks are present in the subsurface and immediately surrounding Fort Laramie National.

Historic Site, the oldest rocks exposed within the boundaries of Fort Laramie NHS are Quaternary river deposits of Pleistocene age (2.58 million to 11,700 years ago) and younger. The only sedimentary deposits within Fort Laramie NHS are the unconsolidated river muds, sands, and gravels of the Laramie and North Platte Rivers. These deposits range from Pleistocene to recent in age. No fossils are known from these deposits, although fossils of Ice Age mammals such as mammoths and bison are known from similar deposits in the region.

Geology Condition Summary

Major geologic resources in Fort Laramie NHS were sedimentary deposits from unconsolidated river muds, sands, and gravels of the Laramie and North Platte Rivers. We assessed condition of sediment transport using a historical comparison of events most likely to move sediment within the park. Seasonal flooding is a natural process, and recent events in the park were within the range of natural variation. On the other hand, flooding can damage park cultural resources and infrastructure, so management of this resource will likely require a balance between natural variation and other park goals. Geologic resources were *Resources in Good Condition*, confidence in condition was *Medium*, and trend was *Not Available* (Table 5.1).

Geology Gaps and Management Issues

Fort Laramie NHS has experienced two 100-year floods in consecutive years and could be subject to higher rates of flooding if climate change increases frequency of high flow events. Continued monitoring would clarify the extent of inter-annual variation in flow and give a basis for projecting how stream flow could change in future climate scenarios.

While geologic conditions in the park may be good, referenced against historical patterns, the cultural resources and infrastructure at Fort Laramie NHS may be at risk. These conditions are outside the scope of this natural resource condition assessment, but cultural resources are of high priority in the founding legislation of the park and are integral to the mission of the park.

Management issues pertaining to geology in the park are most likely to involve the protection and restoration of cultural resources and infrastructure in light of flooding events.

5.4.7. Vegetation

Resource overview from the vegetation reports written by Isabel W. Ashton and Christopher J. Davis (2016):

Fort Laramie National Historic Site, established in 1938 to protect and preserve the well-known military post, covers 833 acres on the boundary of the northern mixed-grass and short-grass prairie region. The park is a mosaic of disturbed old-fields, riparian forests, and native prairie and is host to 376 plant species. The Northern Great Plains Inventory & Monitoring Program (NGPN) began vegetation monitoring at FOLA in 2011. A total of 30 plots were established in FOLA; 15 plots were randomly distributed throughout the park to better study herbaceous plant communities, 15 plots were established in the riparian forest to assess forest condition, and 5 plots were used to study both forest condition and herbaceous plant communities.

<u>Vegetation Condition Summary</u>

A complete vegetation assessment was completed for Fort Laramie NHS in the course of this NRCA, and we based our assessment entirely on those results. Several measures of upland plant community, exotic plant detection, and riparian forest indicated moderate concern. Overall vegetation condition *Warrants Moderate Concern*, confidence in condition was *Medium*, and trend was *Not Available* (Table 5.1).

<u>Vegetation Gaps and Management Issues</u>

Vegetation data for Fort Laramie NHS had few gaps. Continued monitoring will be important in the future. Noxious weeds in the park are prevalent and may require some management decisions in the near future. At the moment, the exotic plant management team can tackle major invasive issues, but the team does not usually begin work at Fort Laramie NHS until August when plants have already released seeds. Additionally, reseeding native plants may be important soon. The park would benefit from having a bio-technician based onsite to focus on plant management.

5.4.8. Birds

Fort Laramie NHS is located within the badlands and prairies bird conservation region (BCR). The badlands and prairies 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 can be found at Fort Laramie NHS. Most grassland bird species are declining in North America. While the overall trend for birds in the badlands and prairies BCR is stable, most of the grassland-obligate species there exhibit negative trends regionally.

Habitat loss is a major cause of grassland bird declines; habitat loss may be related to a reduction in the diversity of native herbivores, such as bison and prairie dogs, which create high quality habitat for many grassland bird species.

Fort Laramie NHS is small, but it contains a variety of habitat types in addition to grasslands. Riparian woodlands within the park are important bird habitat; 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

Fort Laramie NHS is an important stopover point for migratory birds, and tracking those species is of interest to the park (M. Evans, personal communication, 28 September 2016). Sampling occurred in the four years prior to this assessment and will continue through 2018. Continued sampling could be integrated into a natural history program and a citizen science data collection effort.

To identify condition of birds in the park in the future, park management will need to identify management goals. An ongoing natural history program could coordinate with the data collection to monitor species over time.

5.4.9. Bats

Eighteen bat species—of which 13 are fully resident, three are resident in the summer, and two are suspected residents—are known to occur in Wyoming. Many of these bats are of particular concern to the state and are listed as high priority Species of Greatest Conservation Need in the Wyoming State Wildlife Action Plan. Fort Laramie NHS is confirmed as home to at least six species of bat, is suspected to host an additional five species, and could host more species at certain times of the year. Of the 11 species confirmed or suspected in the park, eight have special status from the State of Wyoming and two species (little brown myotis and tri-colored bat) are currently petitioned for listing under the Endangered Species Act.

Bat Condition Summary

Many bats are at risk and sensitive across large portions of their range; we assessed bat condition by looking at condition of 11 individual bat species and the proximity to Wyoming of the nearest known cases of an infectious fungus. Overall condition of bats *Warrants Moderate Concern*, though some species are of higher concern. Confidence in condition was *High*, and trend was *Not Available* (Table 5.1).

Bat Gaps and Management Issues

To detect a change in local bat populations, the most practical approach would be to derive an abundance index from acoustic monitoring. For example, a bat abundance index could be the number of recordings from a species per unit time; repeated annually, this approach could reveal relative changes in bat numbers.

Bat monitoring based on citizen science data collection could be a potential natural resource program. While bats are an important natural resource, they can affect the condition of cultural resources within Fort Laramie NHS. Keeping bats out of old fort buildings is a challenge, and bats can degrade the air quality of the buildings they occupy. Here, park management faces the challenge of simultaneously managing cultural and biological resources that have conflicting management needs.

5.4.10. Pollinators

Wyoming invertebrate pollinators include native insects and honey bees that vary in diversity and abundance across the landscape. The most recent invertebrate survey available for Fort Laramie NHS confirmed that the park is home to a minimum of 16 species, though the authors suggest that the true number of species present is likely to be much higher. Butterflies found within the park included pearl crescent (*Phyciodes tharos*), red admirals (*Vanessa atalanta rubria*), and melissa blue butterflies (*Plebejus melissa*). While bumble bees (*Bombus* sp.) and other invertebrate pollinators are likely present in Fort Laramie NHS, 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 *Warrants 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 Fort Laramie NHS. Following that step, monitoring protocols should be designed so that methods can be consistent among NPS units. Additionally, experts have yet to identify good measures of tolerance and susceptibility to stressors among invertebrate pollinates akin to those that exist for aquatic invertebrates.

As part of the broader effort to draw attention to the natural resources at Fort Laramie NHS, the park has already developed new trail signs that point out presence of butterflies within the park. Citizen science monitoring could contribute to a natural history program focused on pollinators.

Appendix A. Viewshed Details and Figures for Each Vantage Point Included in the Assessment.

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**
FOLA Vantage 1	42.210700, -104.533085	A1
FOLA Vantage 2 (Park Entrance)	42.205332, -104.562609	A2
FOLA Vantage 3	42.205680, -104.557179	A3
FOLA Vantage 4	42.205717, -104.557506	A4
FOLA Vantage 5 (Pony Express Marker)	42.203870, -104.557301	A5
FOLA Vantage 6 (Parade Grounds)	42.202063, -104.558222	A6
FOLA Vantage 7	42.200605, -104.558341	A7
FOLA Vantage 8	42.200795, -104.535822	A8

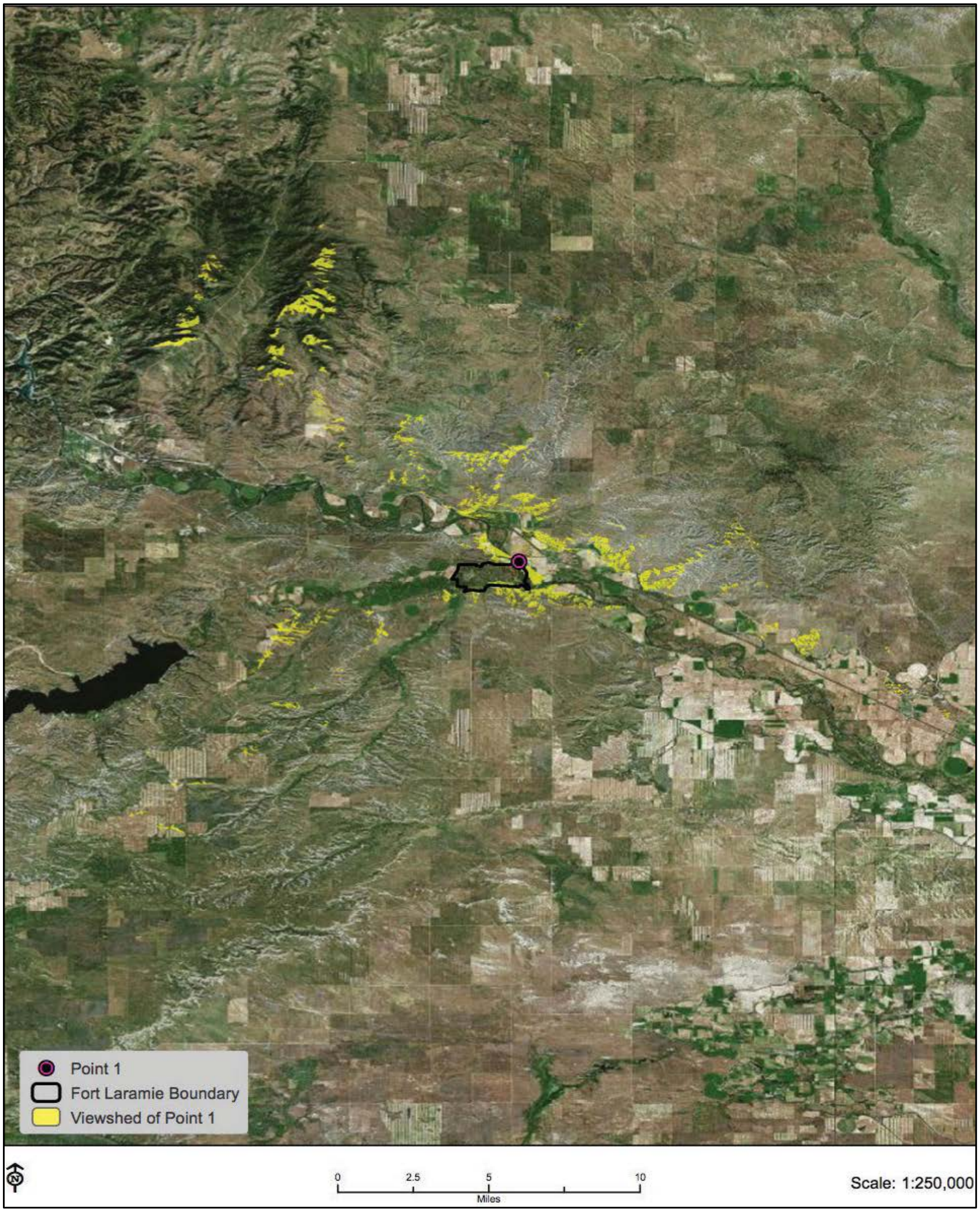


Figure A1. Viewshed for vantage point 1 in Fort Laramie NHS.

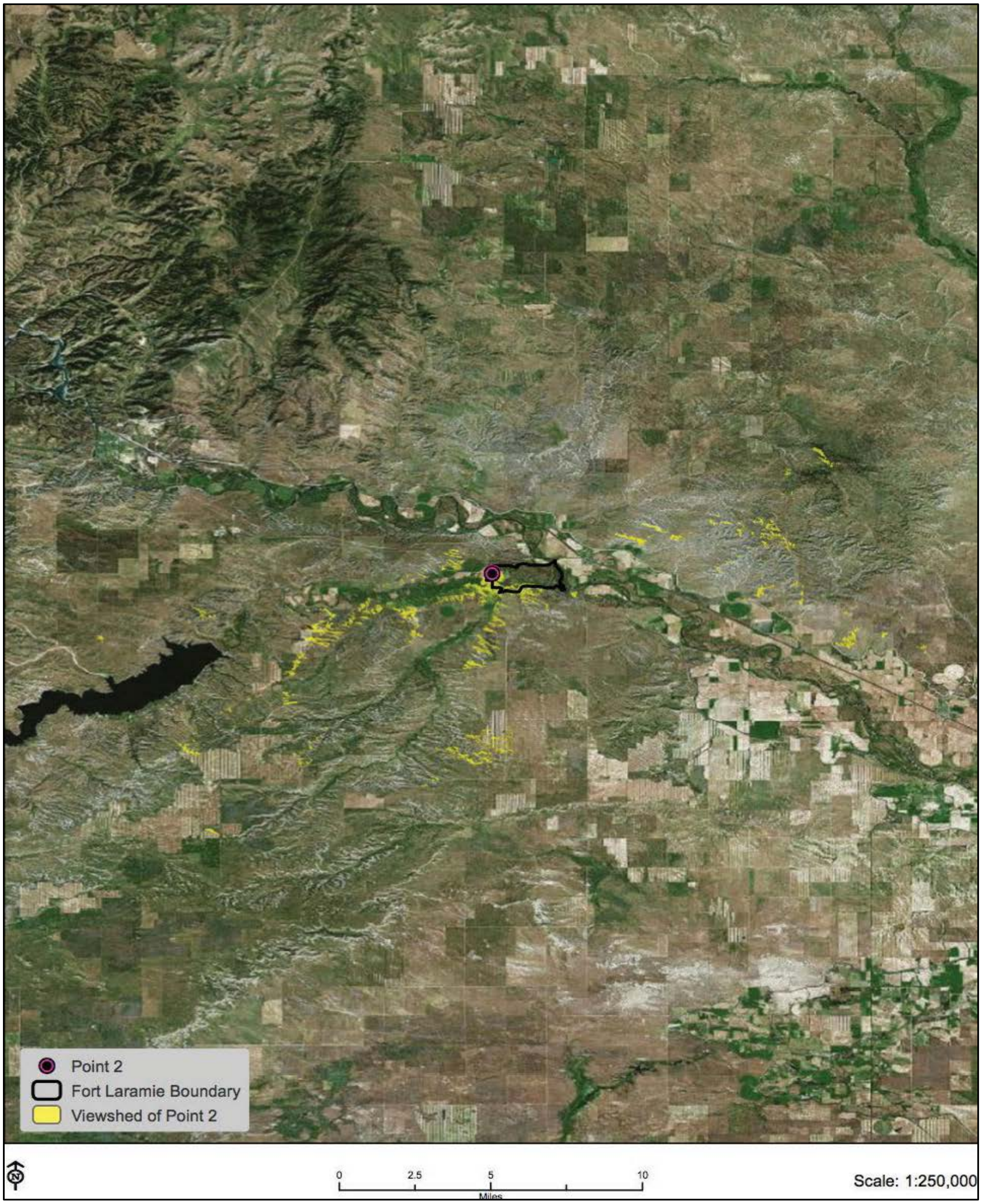


Figure A2. Viewshed for vantage point 2 in Fort Laramie NHS.

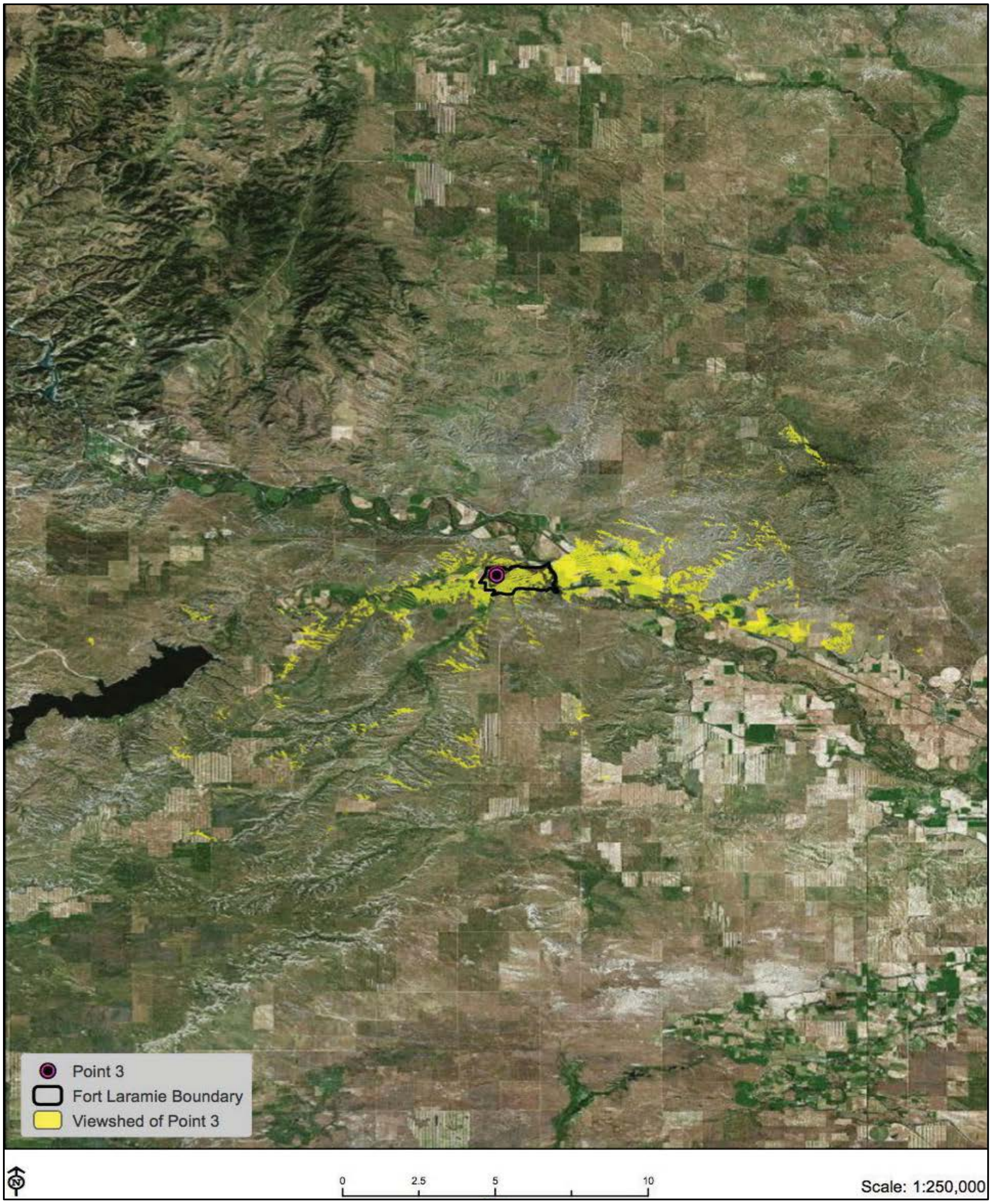


Figure A3. Viewshed for vantage point 3 in Fort Laramie NHS.

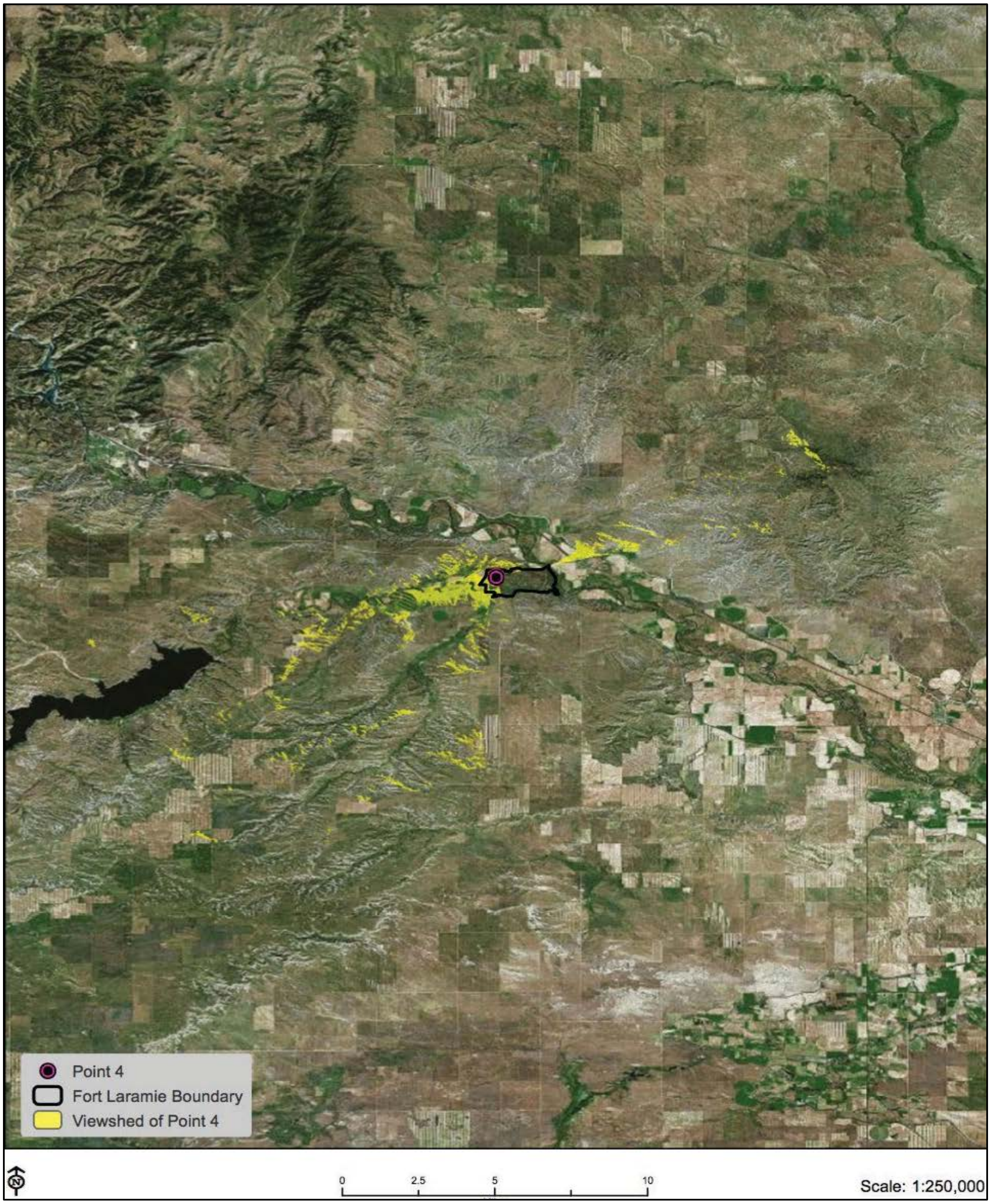


Figure A4. Viewshed for vantage point 4 in Fort Laramie NHS.

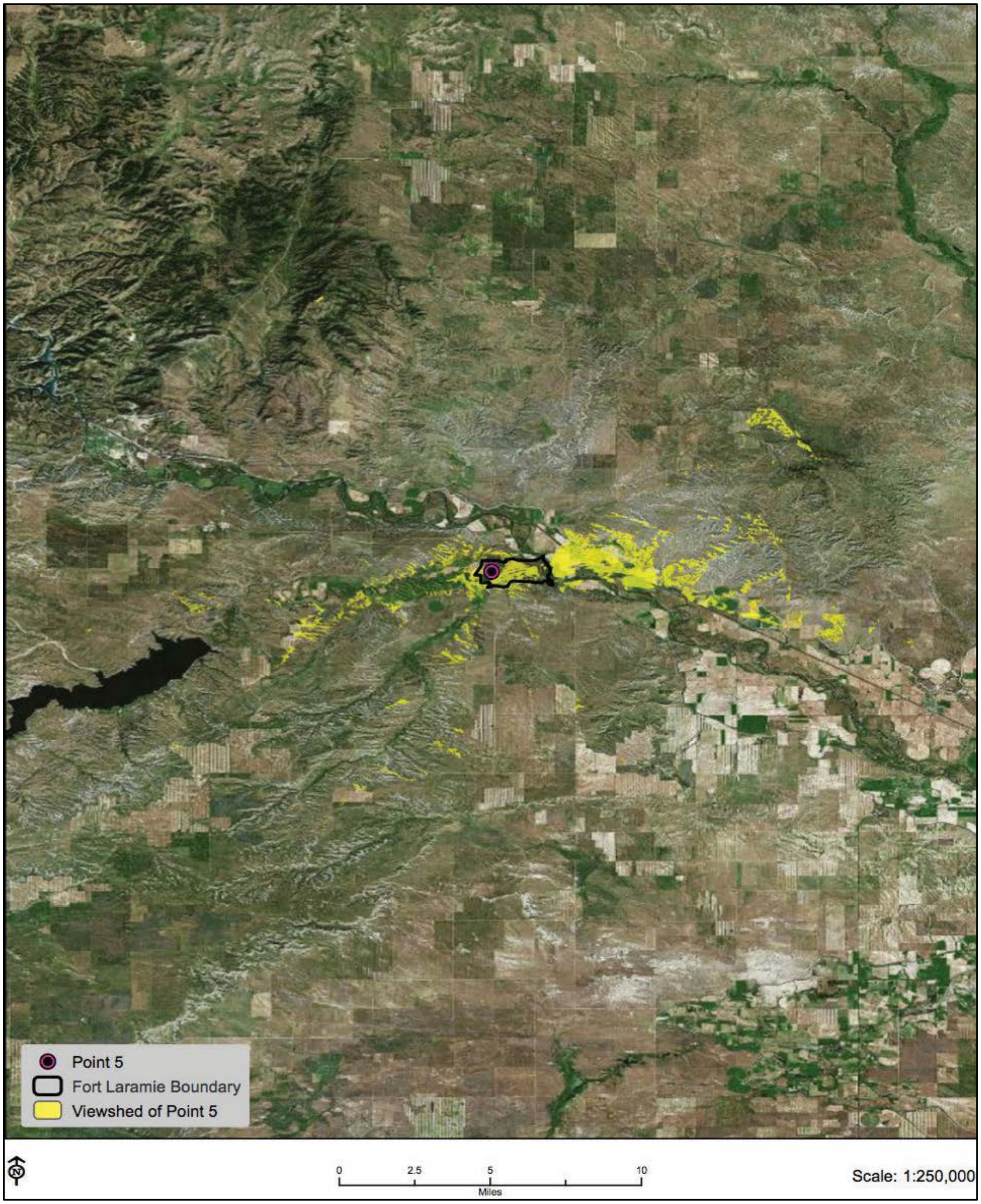


Figure A5. Viewshed for vantage point 5 in Fort Laramie NHS.

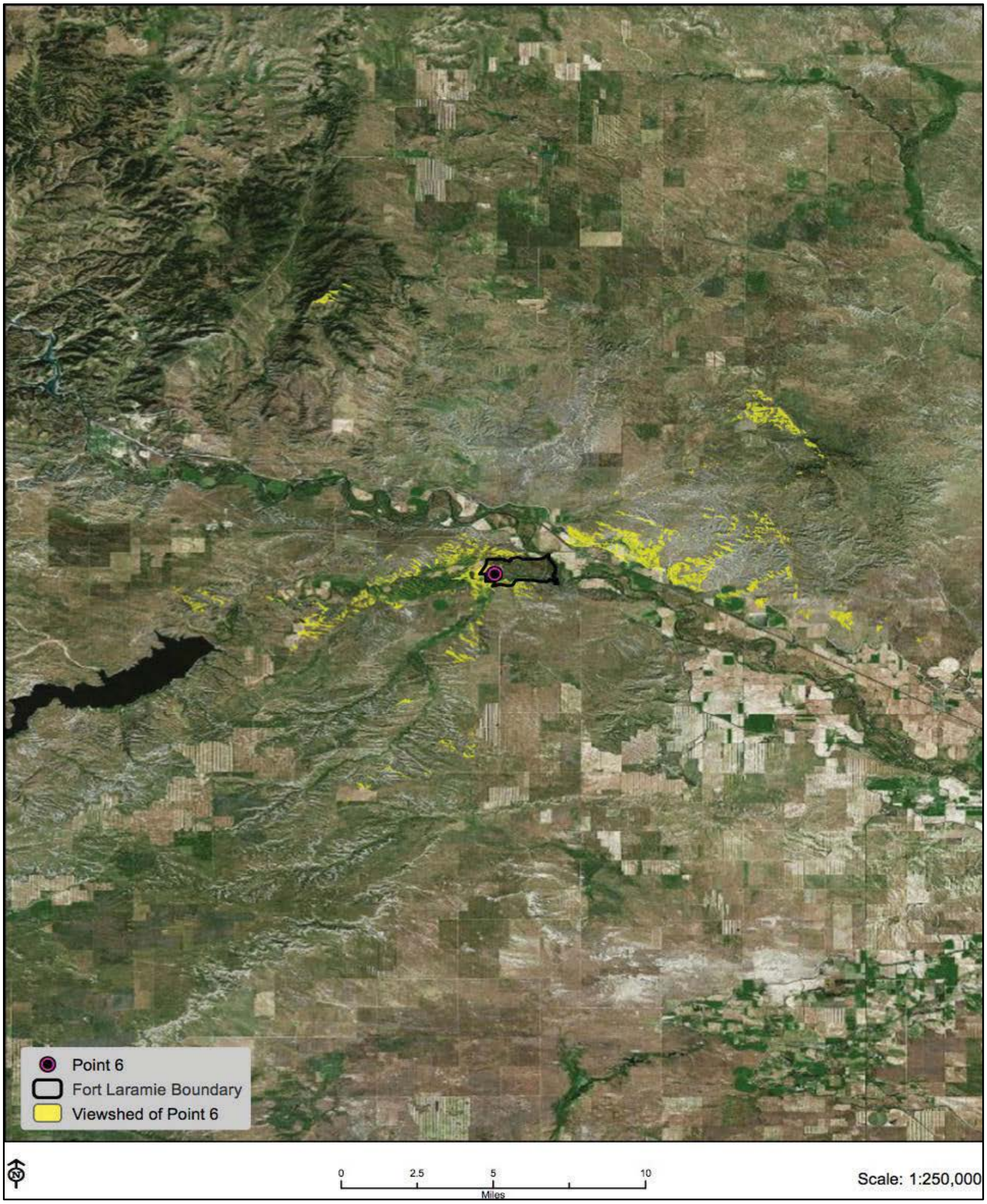


Figure A6. Viewshed for vantage point 6 in Fort Laramie NHS.

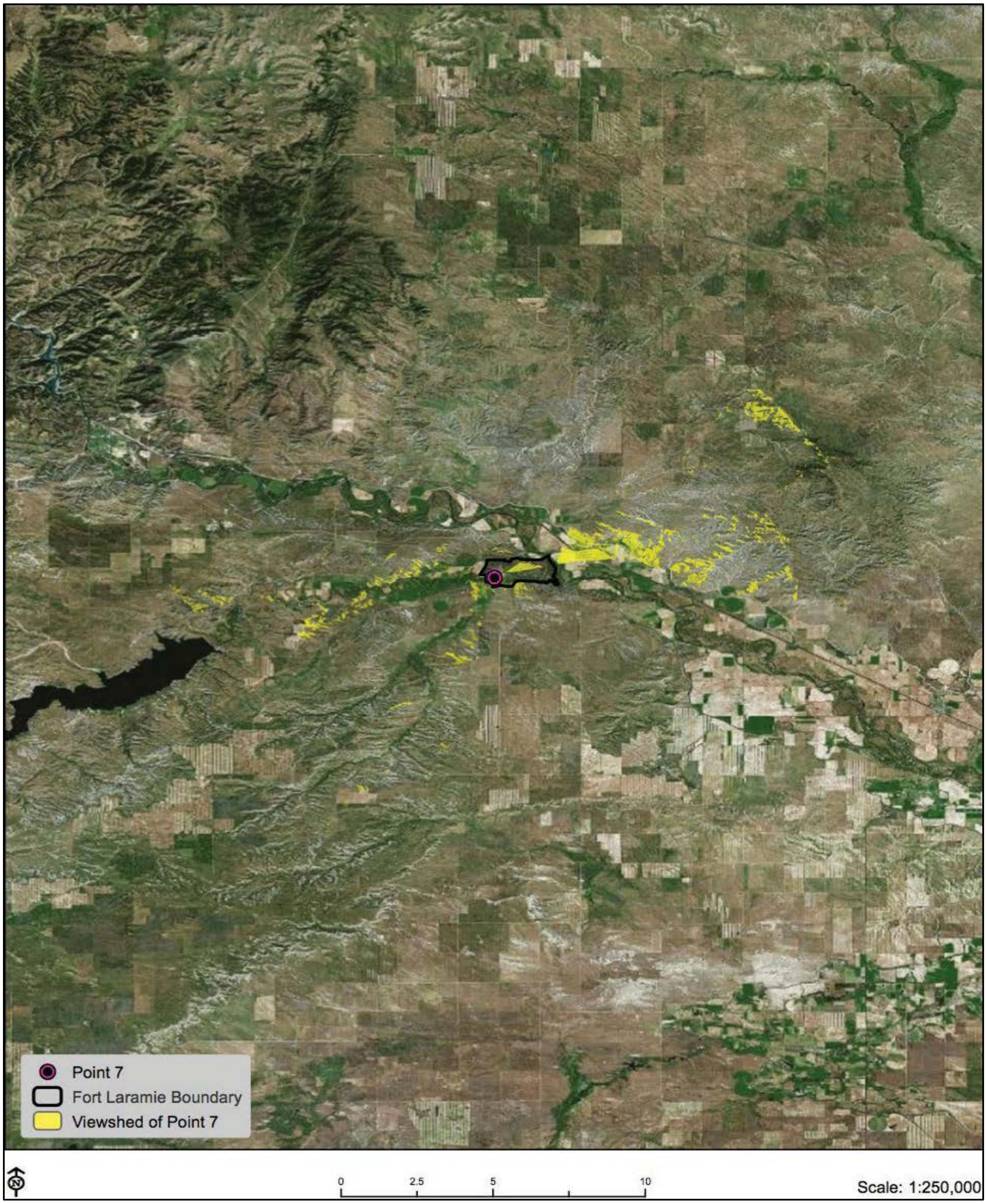


Figure A7. Viewshed for vantage point 7 in Fort Laramie NHS.

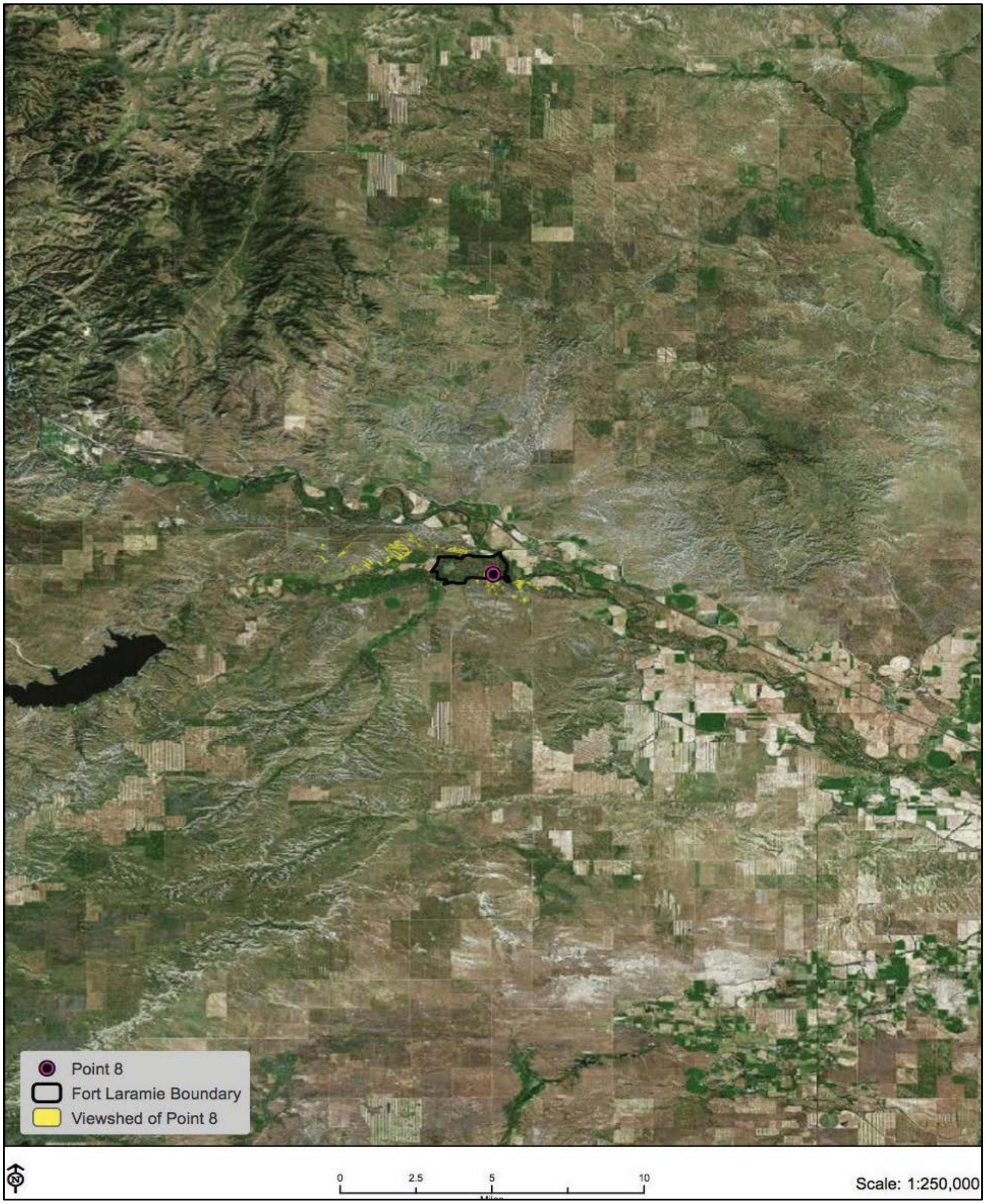


Figure A8. Viewshed for vantage point 8 in Fort Laramie NHS.

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

1. The following steps were followed to achieve the above aim.
2. 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
3. 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.
4. 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.
5. 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.
6. 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 10 m 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 2011-2015 at FOLA.

Below is a list of all the plant species found in FOLA 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 4.7.2 of the report.

Family	Code	Scientific Name	Common Name	Exotic	Rare
Aceraceae	ACNE2	*Acer negundo*	boxelder	–	–
Agavaceae	YUGL	*Yucca glauca*	soapweed yucca	–	–
Amaranthaceae	AMBL	*Amaranthus blitoides*	mat amaranth	X	–
Anacardiaceae	RHTR	*Rhus trilobata*	skunkbush sumac	–	–
	TORY	*Toxicodendron rydbergii*	western poison ivy	–	–
Apiaceae	LOFO	*Lomatium foeniculaceum*	desert biscuitroot	–	–
Apocynaceae	APCA	*Apocynum cannabinum*	Indianhemp	–	–
Asclepiadaceae	ASSP	*Asclepias speciosa*	showy milkweed	–	–
	ASVI	*Asclepias viridiflora*	green comet milkweed	–	–
Asteraceae	AMPS	*Ambrosia psilostachya*	Cuman ragweed	–	–
	AMTO3	*Ambrosia tomentosa*	skeletonleaf burr ragweed	–	–
	ARAB3	*Artemisia absinthium*	absinth wormwood	X	–
	ARBI2	*Artemisia biennis*	biennial sagewort	X	–
	ARCA12	*Artemisia campestris*	field sagewort	–	–
	ARDR4	*Artemisia dracunculus*	tarragon	–	–
	ARFI2	*Artemisia filifolia*	sand sagebrush	–	–
	ARFR4	*Artemisia frigida*	fringed sagewort	–	–
	ARLU	*Artemisia ludoviciana*	white sagebrush	–	–
	BIFR	*Bidens frondosa*	devil's beggartick	–	–
	BITR	*Bidens tripartita*	threelobe beggarticks	–	–
	CIAR4	*Cirsium arvense*	Canada thistle	X	–
	CICA11	*Cirsium canescens*	prairie thistle	X	–
	CIFL	*Cirsium flodmanii*	Flodman's thistle	–	–
	CIVU	*Cirsium vulgare*	bull thistle	X	–
	COCA5	*Conyza canadensis*	horseweed	–	–
	CYXA	*Cyclachaena xanthifolia*	giant sumpweed	–	–
	ERIGE2	*Erigeron* spp.	fleabane	–	–
	EUOC4	*Euthamia occidentalis*	western goldentop	–	–
	GNPA	*Gnaphalium palustre*	western marsh cudweed	–	–
	GRSQ	*Grindelia squarrosa*	curlycup gumweed	–	–
	HEAN3	*Helianthus annuus*	common sunflower	–	–
	HELIA3	*Helianthus* spp.	sunflower	–	–
	HEPE	*Helianthus petiolaris*	prairie sunflower	–	–
	HEVI4	*Heterotheca villosa*	hairy false goldenaster	–	–
	LASE	*Lactuca serriola*	prickly lettuce	X	–

Family	Code	Scientific Name	Common Name	Exotic	Rare
	LYJU	*Lygodesmia juncea*	rush skeletonplant	–	–
	MATA2	*Machaeranthera tanacetifolia*	tanseyleaf tansyaster	–	–
	MUOB99	*Mulgedium oblongifolium*	blue lettuce	–	–
	ONAC	*Onopordum acanthium*	Scotch cottonthistle	X	
	PACA15	*Packera cana*	woolly groundsel	–	–
	PAPL12	*Packera plattensis*	prairie groundsel	–	–
	RACO3	*Ratibida columnifera*	upright prairie coneflower	–	–
	SERI2	*Senecio riddellii*	Riddell's ragwort	–	–
	SYER	*Symphyotrichum ericoides*	white heath aster	–	–
	SYLA6	*Symphyotrichum lanceolatum*	white panicle aster	–	–
	TAOF	*Taraxacum officinale*	common dandelion	X	–
	THME	*Thelesperma megapotamicum*	Hopi tea greenthread	–	–
	TRDU	*Tragopogon dubius*	yellow salsify	X	–
	XAST	*Xanthium strumarium*	rough cockleburr	–	–
Boraginaceae	CRCE	*Cryptantha celosioides*	buttecandle	–	–
	CRMI5	*Cryptantha minima*	little cryptantha	–	–
	CYOF	*Cynoglossum officinale*	houndstongue	X	
	LAOC3	*Lappula occidentalis*	flatspine stickseed	–	–
	LIIN2	*Lithospermum incisum*	narrowleaf stoneseed	–	–
Brassicaceae	ALDE	*Alyssum desertorum*	desert madwort	X	–
	CAMI2	*Camelina microcarpa*	littlepod false flax	X	–
	DEPI	*Descurainia pinnata*	western tansymustard	–	–
	DESO2	*Descurainia sophia*	herb sophia	X	–
	DRRE2	*Draba reptans*	Carolina draba	–	–
	LECA5	*Lepidium campestre*	field pepperweed	X	–
	LEDE	*Lepidium densiflorum*	common pepperweed	–	–
	SIAL2	*Sisymbrium altissimum*	tall tumblemustard	X	–
	THAR5	*Thlaspi arvense*	field pennycress	X	–
Cactaceae	ESVI2	*Escobaria vivipara*	spinystar	–	–
	OPFR	*Opuntia fragilis*	brittle pricklypear	–	–
	OPMA2	*Opuntia macrorhiza*	twistspine pricklypear	–	–
	OPPO	*Opuntia polyacantha*	plains pricklypear	–	–
Capparaceae	PODO3	*Polanisia dodecandra*	redwhisker clammyweed	–	–
Caprifoliaceae	SYOC	*Symphoricarpos occidentalis*	western snowberry	–	–
Chenopodiaceae	CHAL7	*Chenopodium album*	lambsquarters	X	–
	CHBE4	*Chenopodium berlandieri*	pitseed goosefoot	X	–
	CHENO	*Chenopodium* spp.	goosefoot	X	–
	CHFR3	*Chenopodium fremontii*	Fremont's goosefoot	–	–
	KOSC	*Kochia scoparia*	burningbush, kochia	X	–
	KRLA2	*Krascheninnikovia lanata*	winterfat	–	–
	SACO8	*Salsola collina*	slender Russian thistle	X	–

Family	**Code**	**Scientific Name**	**Common Name**	**Exotic**	**Rare**
	SATR12	*Salsola tragus*	prickly Russian thistle	X	–
Commelinaceae	TROC	*Tradescantia occidentalis*	prairie spiderwort	–	–
Convolvulaceae	COAR4	*Convolvulus arvensis*	field bindweed	X	–
	IPLE	*Ipomoea leptophylla*	bush morning-glory	–	–
Cyperaceae	CADU6	*Carex duriuscula*	needleleaf sedge	–	–
	CAEM2	*Carex emoryi*	Emory's sedge	–	S1
	CAFI	*Carex filifolia*	threadleaf sedge	–	–
	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	–	–
	CAREX	*Carex* spp.	sedge	–	–
	CYSQ	*Cyperus squarrosus*	bearded flatsedge	–	–
	ELAC	*Eleocharis acicularis*	needle spikerush	–	–
	ELPA3	*Eleocharis palustris*	common spikerush	–	–
	SCPU10	*Schoenoplectus pungens*	common threesquare	–	–
	SCTA2	*Schoenoplect us tabernaemont ani*	softstem bulrush	–	–
Elaeagnaceae	ELAN	*Elaeagnus angustifolia*	Russian olive	X	–
	SHAR	*Shepherdia argentea*	silver buffaloberry	–	–
Equisetaceae	EQLA	*Equisetum laevigatum*	smooth horsetail	–	–
Euphorbiaceae	CRTE4	*Croton texensis*	Texas croton	–	–
	EUPHO	*Euphorbia* spp.	spurge, sandmat	X	–
	EUGL3	*Euphorbia glyptosperma*	ribseed sandmat	–	–
	EUSE5	*Euphorbia serpyllifolia*	thymeleaf sandmat	–	–
Fabaceae	AMFR	*Amorpha fruticosa*	desert false indigo	–	–
	DACA7	*Dalea candida*	white prairie clover	–	–
	GLLE3	*Glycyrrhiza lepidota*	American licorice	–	–
	GLTR	*Gleditsia triacanthos*	honeylocust	–	–
	LAPO2	*Lathyrus polymorphus*	manystem pea	–	–
	LUPU	*Lupinus pusillus*	rusty lupine	–	–
	MELU	*Medicago lupulina*	black medick	X	–
	MEOF	*Melilotus officinalis*	yellow sweetclover	X	–
	MESA	*Medicago sativa*	alfalfa	X	–
	PEES	*Pediomelum esculentum*	large Indian breadroot	–	–
	PSTE5	*Psoralidium tenuiflorum*	slimflower scurfpea	–	–
	TRFR2	*Trifolium fragiferum*	strawberry clover	X	–
Fumariaceae	COCU2	*Corydalis curvisiliqua*	curvepod fumewort	–	–
Grossulariaceae	RIAU	*Ribes aureum*	golden currant	–	–
	RICE	*Ribes cereum*	wax currant	–	–

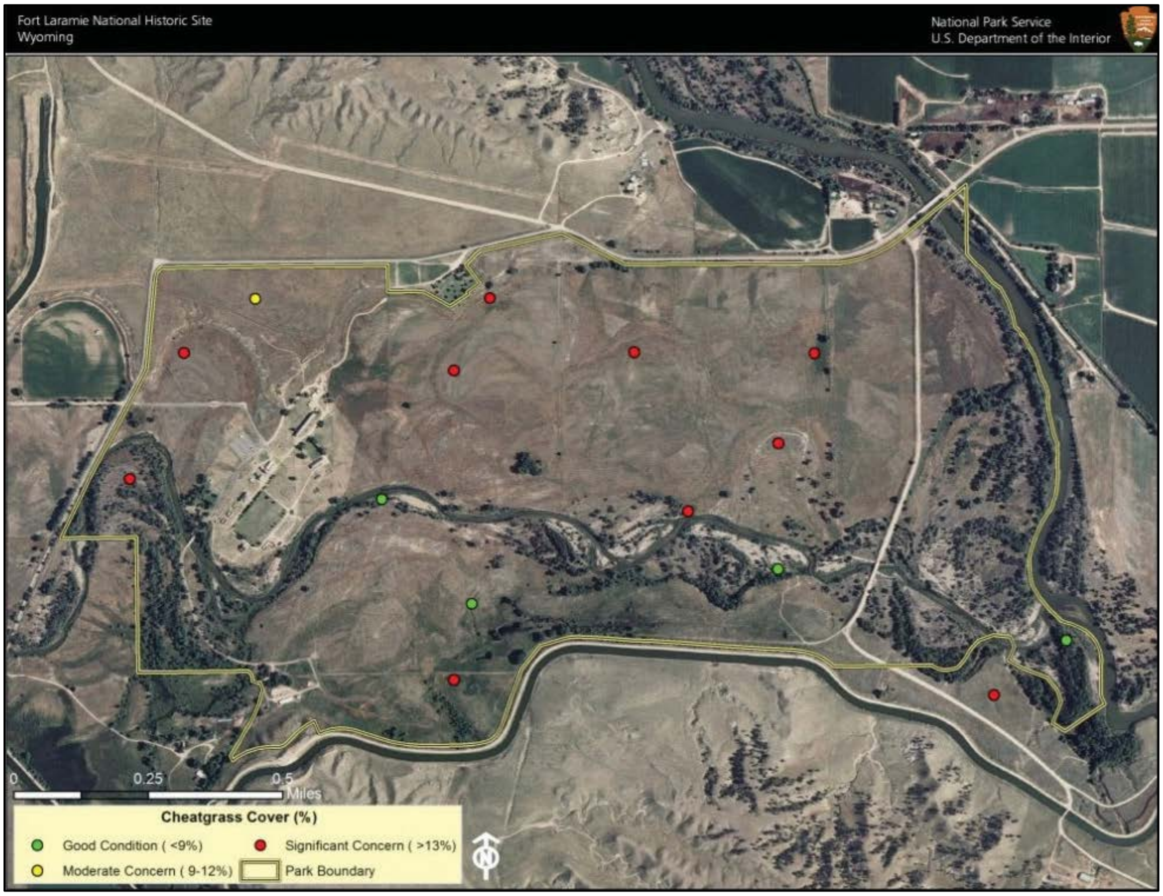
Family	Code	Scientific Name	Common Name	Exotic	Rare
Hydrophyllaceae	ELNY	*Ellisia nyctelea*	Aunt Lucy	–	–
Juncaceae	JUBA	*Juncus balticus*	Baltic rush	–	–
	JUCO	*Juncus compressus*	roundfruit rush	X	–
Lamiaceae	LYAM	*Lycopus americanus*	American water horehound	–	–
	LYAS	*Lycopus asper*	rough bugleweed	–	–
	MEAR4	*Mentha arvensis*	wild mint	–	–
	NECA2	*Nepeta cataria*	catnip	X	
	TECA3	*Teucrium canadense*	Canada germander	–	–
Lemnaceae	LETU2	*Lemna turionifera*	turion duckweed	–	–
Liliaceae	ALTE	*Allium textile*	textile onion	–	–
Loasaceae	MEDE2	*Mentzelia decapetala*	tenpetal blazingstar	–	–
Malvaceae	SPCO	*Sphaeralcea coccinea*	scarlet globemallow	–	–
Nyctaginaceae	MIHI	*Mirabilis hirsuta*	hairy four o'clock	–	–
	MILI3	*Mirabilis linearis*	narrowleaf four o'clock	–	–
Oleaceae	FRPE	*Fraxinus pennsylvanica*	green ash	–	–
Onagraceae	OEAL	*Oenothera albicaulis*	whitest evening-primrose	–	–
	OECU2	*Oenothera curtiflora*	velvetweed	–	–
	OENOT	*Oenothera* spp.	evening-primrose	–	–
	OESE3	*Oenothera serrulata*	yellow sundrops	–	–
	OESU99	*Oenothera suffrutescens*	scarlet beeblossom	–	–
	OEVI	*Oenothera villosa*	hairy evening primrose	–	–
Papaveraceae	ARPO2	*Argemone polyanthemos*	crested pricklypoppy	–	–
Plantaginaceae	PLMA2	*Plantago major*	common plantain	–	–
	PLPA2	*Plantago patagonica*	woolly plantain	–	–
Poaceae	ACHY	*Achnatherum hymenoides*	Indian ricegrass	–	–
	AGCR	*Agropyron cristatum*	crested wheatgrass	X	–
	AGST2	*Agrostis stolonifera*	creeping bentgrass	–	–
	ARPU9	*Aristida purpurea*	purple threeawn	–	–
	BOCU	*Bouteloua curtipendula*	sideoats grama	–	–
	BODA2	*Bouteloua dactyloides*	buffalograss	–	–
	BOGR2	*Bouteloua gracilis*	blue grama	–	–
	BRIN2	*Bromus inermis*	smooth brome	X	–
	BRJA	*Bromus japonicus*	Japanese brome	X	–
	BRTE	*Bromus tectorum*	cheatgrass	X	–
	CALO	*Calamovilfa longifolia*	prairie sandreed	–	–
	ECCR	*Echinochloa crus-galli*	barnyardgrass	X	–
	ELCA4	*Elymus canadensis*	Canada wildrye	–	–
	ELRE4	*Elymus repens*	quackgrass	X	–
	ELTR7	*Elymus trachycaulus*	slender wheatgrass	–	–
	HECO26	*Hesperostipa comata*	needle and thread	–	–
	HOBR2	*Hordeum brachyantherum*	meadow barley	–	–
	KOMA	*Koeleria macrantha*	prairie Junegrass	–	–
	MUPA99	*Muhlenbergia paniculata*	tumblegrass	–	–

Family	Code	Scientific Name	Common Name	Exotic	Rare
	NAVI4	*Nassella viridula*	green needlegrass	–	–
	PACA6	*Panicum capillare*	witchgrass	–	–
	PASM	*Pascopyrum smithii*	western wheatgrass	–	–
	PAVI2	*Panicum virgatum*	switchgrass	–	–
	PHAR3	*Phalaris arundinacea*	reed canarygrass	X	–
	PHPR3	*Phleum pratense*	timothy	X	–
	POCO	*Poa compressa*	Canada bluegrass	X	–
	POPR	*Poa pratensis*	Kentucky bluegrass	X	–
	PSSP6	*Pseudoroegneria spicata*	bluebunch wheatgrass	–	–
	SCSC	*Schizachyrium scoparium*	little bluestem	–	–
	SEVI4	*Setaria viridis*	green bristlegrass	X	–
	SPCR	*Sporobolus cryptandrus*	sand dropseed	–	–
	SPPE	*Spartina pectinata*	prairie cordgrass	–	–
	VUOC	*Vulpia octoflora*	sixweeks fescue	–	–
Polygonaceae	ERAN4	*Eriogonum annuum*	annual buckwheat	–	–
	EREF	*Eriogonum effusum*	spreading buckwheat	–	–
	PEAM8	*Persicaria amphibia*	longroot smartweed	–	–
	PEMA24	*Persicaria maculosa*	spotted ladysthumb	X	–
	PERSI99	*Persicaria* spp.	smartweed	X	–
	PELA22	*Persicaria lapathifolia*	curlytop knotweed	–	–
	RUCR	*Rumex crispus*	curly dock	X	–
	RUMEX	*Rumex* spp.	dock	X	–
Ranunculaceae	RACY	*Ranunculus cymbalaria*	alkali buttercup	–	–
Rosaceae	POSU25	*Potentilla supina*	Paradox cinquefoil	–	–
	PRAM	*Prunus americana*	American plum	–	–
	PRVI	*Prunus virginiana*	chokecherry	–	–
	ROAR3	*Rosa arkansana*	prairie rose	–	–
Rubiaceae	GAAP2	*Galium aparine*	stickywilly	–	–
	GATR3	*Galium triflorum*	fragrant bedstraw	–	–
Salicaceae	POAN3	*Populus angustifolia*	narrowleaf cottonwood	–	–
	PODE3	*Populus deltoides*	eastern cottonwood	–	–
	SAAM2	*Salix amygdaloides*	peachleaf willow	–	–
	SAEX	*Salix exigua*	narrowleaf willow	–	–
	SAFR	*Salix fragilis*	crack willow	X	–
Scrophulariaceae	VEAN2	*Veronica anagallis-aquatica*	water speedwell	–	–
	VETH	*Verbascum thapsus*	common mullein	X	–
Solanaceae	PHLO4	*Physalis longifolia*	longleaf groundcherry	–	–
	SORO	*Solanum rostratum*	buffalobur nightshade	–	–
Tamaricaceae	TACH2	*Tamarix chinensis*	five-stamen tamarisk	X	–
Typhaceae	TYAN	*Typha angustifolia*	narrowleaf cattail	X	–
Urticaceae	PAPE5	*Parietaria pensylvanica*	Pennsylvania pellitory	–	–
Verbenaceae	PHCU3	*Phyla cuneifolia*	wedgeleaf	–	–

Family	Code	Scientific Name	Common Name	Exotic	Rare
	VEBR	*Verbena bracteata*	bigbract verbena	–	–
	VEHA2	*Verbena hastata*	swamp verbena	–	–
Vitaceae	PAVI5	*Parthenocissus vitacea*	woodbine	–	–
	VIRI	*Vitis riparia*	riverbank grape	–	–

Appendix D. Natural Resource Condition Maps of Exotic Species at FOLA.

The map below illustrates the abundance of cheatgrass (*Bromus tectorum*) and smooth brome (*B. inermis*) in monitoring plots at Fort Laramie National Historic Site. Red indicates relative cover of > 13% and is a significant concern.



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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