National Park Service
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Natural Resource Stewardship and Science

Natural Resource Condition Assessment

Petrified Forest National Park (Revised with Costs)

Natural Resource Report NPS/PEFO/NRR—2020/2186

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ON THE COVER
Milky Way over Battleship Rock, Petrified Forest National Park
Jacob Holgerson, NPS

Natural Resource Condition Assessment

Petrified Forest National Park (Revised with Costs)

Natural Resource Report NPS/PEFO/NRR—2020/2186

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Executive Summary

The Natural Resource Condition Assessment (NRCA) Program, administered by the National Park Service's (NPS) Washington Support Office, Denver Service Center Planning Division, provides documentation about current conditions of important park natural resources through a spatially explicit, multidisciplinary synthesis of existing scientific data and knowledge. The workshop for Petrified Forest National Park (PEFO) NRCA was held on 02-04 September 2015.

PEFO was originally established as a national monument in 1906 by President Theodore Roosevelt. Designated a national park in 1962, these lands were recognized as a national park unit because of the fossilized remains of Mesozoic forests that were of the great scientific value and by preserving these fossils, the public good would be promoted (NPS 2015). This body of literature and research was used to report on current conditions for the 14 natural resource topics park staff selected for its NRCA.

These 14 natural resources (with 41 indicators) were grouped into three broad categories: landscape-scale, supporting environment (i.e., physical resources), and biological integrity. The latter included chapters on wildlife and vegetation. This NRCA includes an assessment of condition and trend for key resources determined by assessing multiple indicators for each focal resource (Chapter 4). A summary is provided for each resource category below. Most indicators were identified as currently in good condition (14 indicators) or warranting moderate concern (10); additionally, 14 indicators were identified as unknown or indeterminate based on a lack of information to complete the assessment. The most significantly impacted resources included air quality and the acoustic environment. The only natural resources considered to be in good condition were biodiversity, although most of the indicators rated at this level were indicative of inventory work into either diversity or habitat was largely completed; all of substantive indicators related to indicator species, the effects of alien plant species on ecosystem health or bait roost habitat were unknown or indeterminate. Indicator symbols and examples are shown in Tables E.1-1 and E.1-2. All condition and trend information is displayed per indicator in Tables E.1-3 through E.1-6. A detailed discussion of each indicator is provided in Ch. 4.

Because PEFO is a non-urban park, current and future threats are more associated with increased visitation and issues associated with growing population centers at considerable distances from the park's boundary. Acoustic environment received a "significant concern" rating, which is primarily due to vehicular traffic. As visitation increases, the condition of the acoustic environment will be further eroded—unless efforts are ultimately taken to limit the number of vehicles on park roads. Air quality and night skies will continue to be challenged by the growing population centers of Flagstaff, Arizona and Gallup, New Mexico, and the expanding metropolitan areas of Phoenix, Arizona and Albuquerque, New Mexico. Unless these population centers address air and light pollution, improving these conditions at PEFO will be beyond the park's control.

Table E.1-1. Indicator symbols used to indicate condition, trend, and confidence in the assessment.

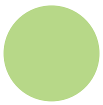
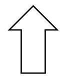
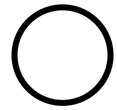
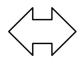
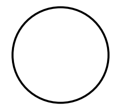
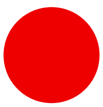
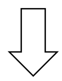
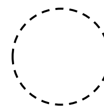
Condition Status		**Trend in Condition**		**Confidence in Assessment**	
Condition Icon	**Condition Icon Definition**	**Trend Icon**	**Trend Icon Definition**	**Confidence Icon**	**Confidence Icon Definition**
	Resource is in Good Condition		Condition is Improving		High
	Resource warrants Moderate Concern		Condition is Unchanging		Medium
	Resource warrants Significant Concern		Condition is Deteriorating		Low

Table E.1-2. Example indicator symbols with verbal descriptions.

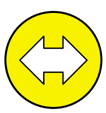
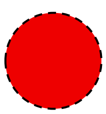
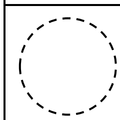
Symbol Example	**Verbal Description**
	Resource is in good condition; its condition is improving; high confidence in the assessment.
	Condition of resource warrants moderate concern; condition is unchanging; medium confidence in the assessment.
	Condition of resource warrants significant concern; trend in condition is unknown or not applicable; low confidence in the assessment.
	Current condition is unknown or indeterminate due to inadequate data, lack of reference value(s) for comparative purposes, and/or insufficient expert knowledge to reach a more specific condition determination; trend in condition is unknown or not applicable; low confidence in the assessment.

Table E.1-3. Summary of resources identified as in "good condition".

Resource is in Good Condition		
Trend	**Resource**	**Indicator**
Condition is deteriorating.	None	N/A
Condition is unchanging	Grasslands	Grassland community extent
	Grasslands	Native grassland species richness and composition
	Gunnison prairie dog	Available suitable habitat
	Grassland birds	Habitat extent
	Grassland birds	Native grassland bird species richness and composition
	Bats	Bat species richness
Condition is improving	Air quality	Wet deposition of Sulfur
	Riparian	Native riparian composition and structure
	Riparian	Tamarisk occurrence and distribution (reduction thereof)
	Gunnison prairie dog	Colony extent
Unknown	Viewshed	Scenic Inventory Value
	Viewshed	Non-contributing man-made buildings and infrastructure
	Reptiles & amphibians	Amphibian species richness
	Reptiles & amphibians	Reptile species richness

Table E.1-4. Summary of resources identified to warrant "moderate concern".

Resource Condition Warrants Moderate Concern		
Trend	**Resource**	**Indicator**
Condition is deteriorating.	None	N/A
Condition is unchanging	Air quality	Ozone
	Hydrogeology	Alluvial water quality

Table E.1-4 (continued). Summary of resources identified to warrant "moderate concern".

Resource Condition Warrants Moderate Concern		
Trend	Resource	Indicator
Condition is improving	Air quality	Visibility
Unknown	Night skies	Bortle sky classification
	Night skies	Zenith sky brightness
	Paleontology & geology	Erosion/ infrastructure damage in bentonite areas
	Paleontology & geology	Potash extraction
	Grasslands	Non-native alien plant species occurrence
	Grasslands	Ratio of native to alien plant species
	Alien plants	Alien plants with high or medium invasiveness ranking

Table E.1-5. Summary of resources identified to warrant "significant concern".

Resource Condition Warrants Significant Concern		
Trend	**Resource**	**Indicator**
Condition is deteriorating.	None	N/A
Condition is unchanging	Air quality	Vegetation health
	Air quality	Wet deposition of Nitrogen
Condition is improving	None	N/A
Unknown	Acoustic environment	Percent reduction in listening area

Table E.1-6. Summary of resources identified as condition "unknown" or "indeterminate".

Current Condition is Unknown or Indeterminate		
Trend	**Resource**	**Indicator**
Unknown/ Indeterminate	Night skies	Zenith limiting magnitude
	Acoustic environment	Percent time audible
	Paleontology & geology	Damage to paleontological resources
	Paleontology & geology	Petrified wood theft
	Soil crusts	Damage to soil crusts
	Alien plants	Change in percent cover of alien plant species
	Alien plants	Distribution of alien plants
	Alien plants	Recovery of tamarisk-treated areas
	Grassland birds	Indicator species
	Bats	Summer roost occurrence
	Bats	Hibernacula roost occurrence
	Reptiles & amphibians	Amphibian habitat extent

Chapter 1. NRCA Background Information

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

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

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

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

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

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

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

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

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

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

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

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

The credibility of NRCA results is derived from the data, methods, and reference values used in the project work, which are designed to be appropriate for the stated purpose of the project, as well as adequately documented. For each study indicator for which current condition or trend is reported, we will identify critical data gaps and describe the level of confidence in at least qualitative terms. Involvement of park staff and National Park Service (NPS) subject-matter experts at critical points during the project timeline is also important. These staff were 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.

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[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

In this document, Petrified Forest National Park is referred to as PEFO, "Petrified Forest" or "the park" (Fig. 2.0-1).

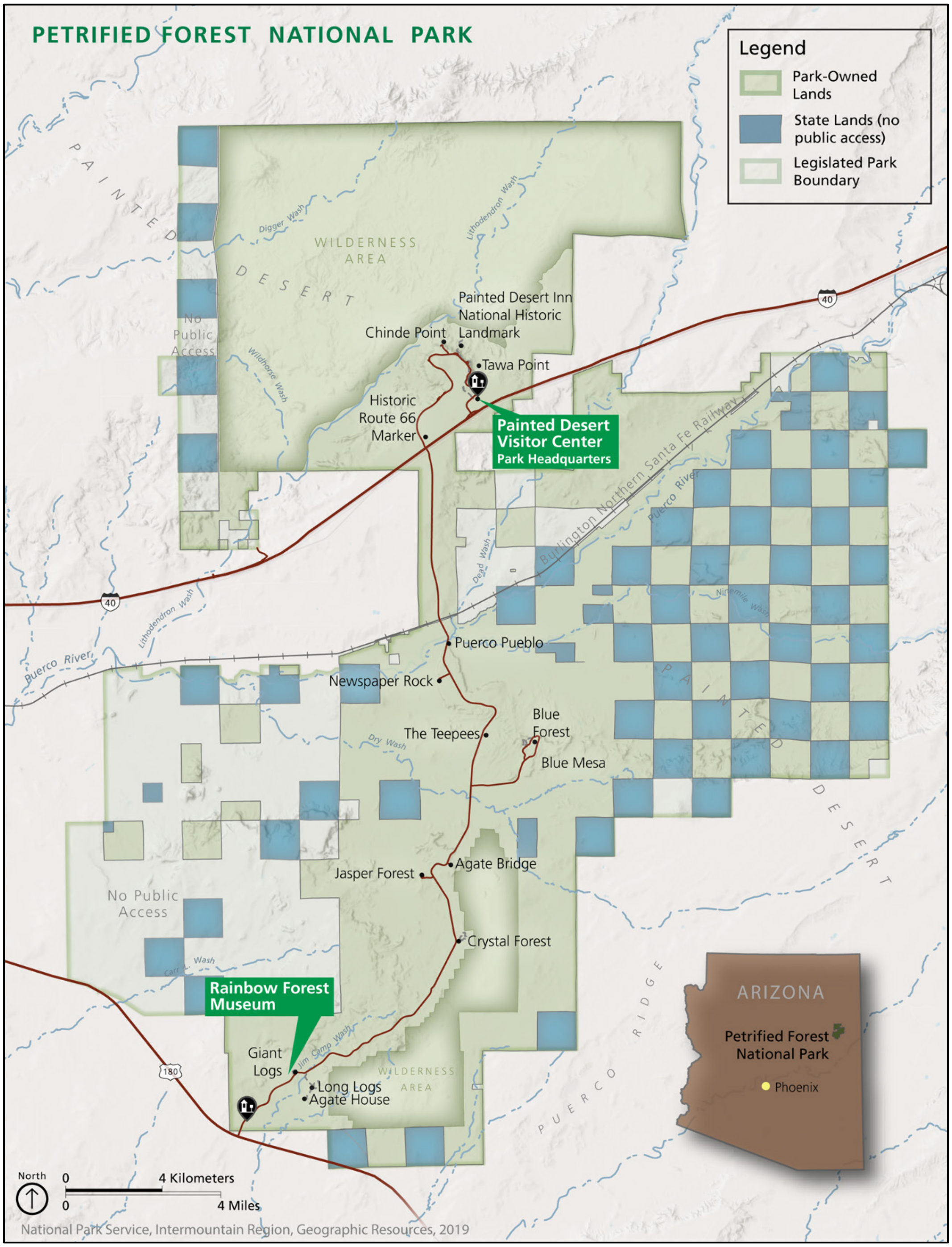


Figure 2.0-1. PEFO with the current park boundary presented. (NPS, Intermountain Region, Geographic Resources, Denver, Colorado).

2.1. Introduction

2.1.1. Enabling Legislation

Petrified Forest National Park was designated in 1906 by President Theodore Roosevelt under authority granted to him by the Antiquities Act of 1906 to preserve areas of scenic, scientific, and educational interest for current and future generations (NPS 2006a).

The primary reason for park establishment was the fossilized remains of Mesozoic forests that were of the "greatest scientific interest and value and…that the public good would be promoted" by preserving these resources (Proclamation No. 697). President Roosevelt initially designated these lands as a National Monument.

Since its designation in 1960, PEFO has undergone a number of boundary revisions. The original monument designation included about 50,000 acres (20,234 ha). In 1932, approximately 2,500 acres were added bringing the total to 93,442 acres (~37,815 ha; Colbert and Johnson 1981). In 1962, the monument was designated as a national park (Colbert and Johnson 1981). To better protect its natural resources, more than 53% of the park was designated as wilderness in 1970 (Colbert and Johnson 1981). The park area more than doubled in 2004, and now consists of 225,000 acres (91,054 ha; NPS 2016). While primary priorities for park expansion was to preserve paleontological and archaeological resources, the "first view" of the Painted Desert, which park visitors see approaching from the west on Interstate 40, was also preserved (NPS 2006a).

2.1.2. Geographic Setting

Located in northeastern Arizona in Navajo and Apache counties, the park is bisected by Interstate 40 and the Burlington Northern Santa Fe Railway. Elevations range from 5300 to 6235 ft (1615 m to 1900 m) with most of the park occurring at approximately 5500 ft (1767 m). While occurring within the southern Colorado Plateau, the park falls within the Puerco River Valley, which is part of the Little Colorado River drainage. The diversity of geologic and soil types contribute to a corresponding diversity in vegetation types.

<u>Population</u>

PEFO is surrounded by sparsely populated small towns to the east, west and south, and the Navajo Nation Reservation to the north. Surrounding human populations outside of the Navajo Nation include Holbrook (5,049), Snowflake (5,753) and St. Johns (3,508; USCB 2019), while the Navajo Nation has a population of roughly 350,000 largely spread out across 27,413 sq mi (71,000 km^2).

<u>Climate</u>

The climate of the U.S. Southwest is most influenced by its location between the mid-latitude and subtropical atmospheric circulation regimes. This creates the typical southwestern climate of dry, sunny days (low annual precipitation) and warmer temperatures year round. Monsoonal-driven precipitation occurs from July through September originating in the Pacific Ocean and the Gulf of Mexico. Winter precipitation occurs from November through March following an eastern storm track from the Pacific Ocean (Sheppard et al. 2002).

The Colorado Plateau, which is where the park is situated, is an arid region characterized by irregular rainfall, periods of drought, warm to hot growing seasons, and long winters with freezing temperatures (Davey et al. 2006). Due to the immensity of this geographic area and the variation in topography, the climate conditions within the southern Colorado Plateau are influenced by both elevation and latitude.

Temperature

Temperature at PEFO ranges from an average low of 47.5° F during winter to an average high of 92.4° F (Period of Record, 01/01/1931 to 06/09/2016; WRCC 2018). Warm season is typically from May–September with colder temperatures occurring from November through February. Figure 2-2 depicts average maximum and minimum temperatures from 01/01/1931 through 06/09/2016 (WRCC 2018).

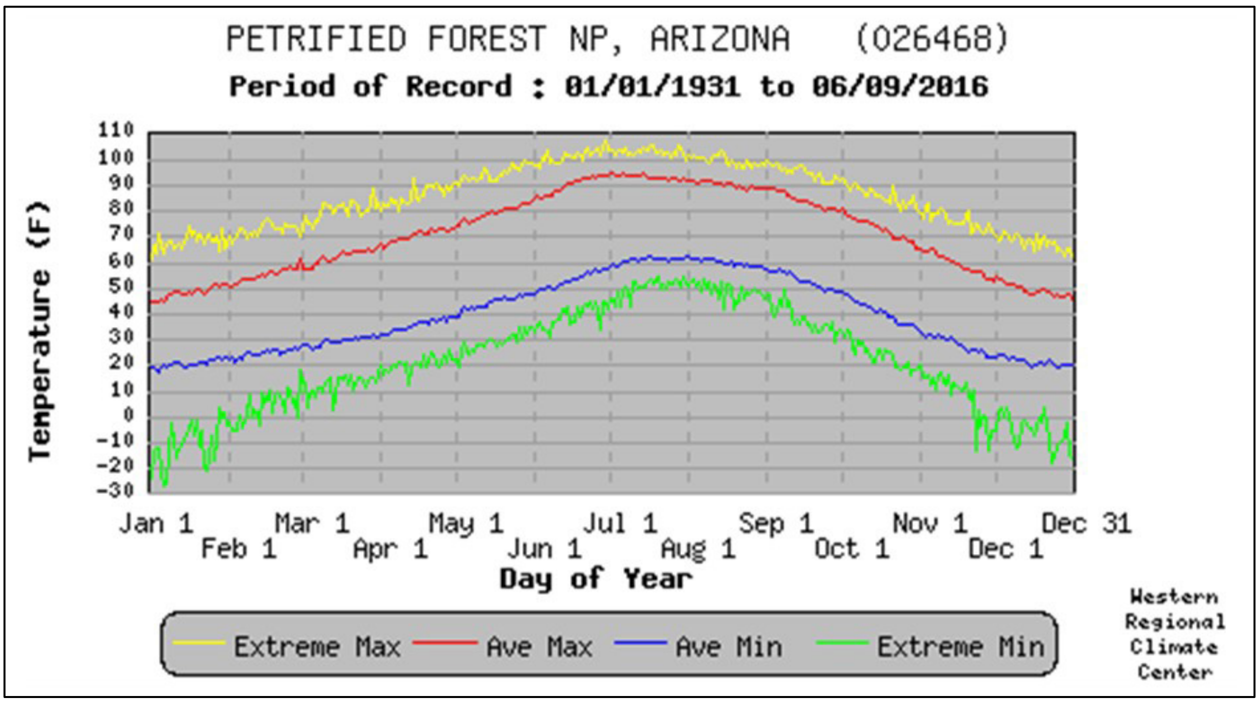


Figure 2.1-1. Monthly average temperature (°F) from 01 January 1931 through 09 June 2016, Petrified Forest National Forest, Arizona (WRCC 2018).

Precipitation

Petrified Forest National Park was receives precipitation from both summer monsoons and winter storms with more precipitation occurring during the summer than winter. Regionally, average precipitation on the Colorado Plateau is 10 to 35 inches per year (Figure 2.1-2A.). At PEFO, average rainfall is between 0.5 and 1.7 inches per year (Figure 2.1-2B.). Between 1931 and 2012, the average precipitation was 2.54 inches of rainfall (Table 2.2-1; WRCC 2018) and 1.95 inches of snowfall (Table 2.2-2; WRCC 2018).

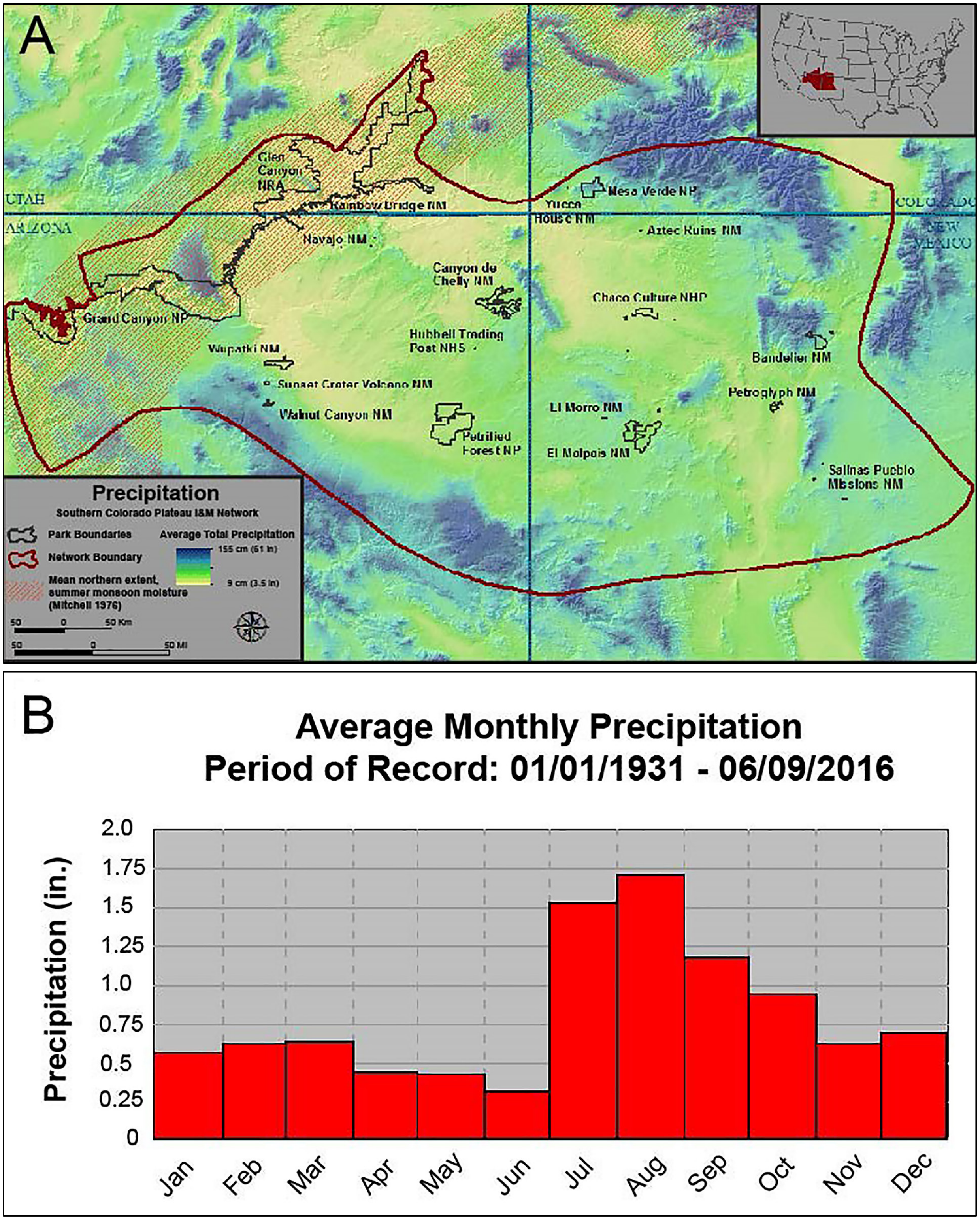


Figure 2.1-2. (A) Precipitation gradient model produced by NPS Southern Colorado Plateau Inventory and Monitoring Network for the southern Colorado Plateau, U.S. (B) Average monthly precipitation from on-site monitoring (weather station #026468) from 01/01/1931 through 06/09/2016. (NPS Western Regional Climate Center for Petrified Forest National Park, AZ).

Table 2.2-1. Rainfall records (in inches) from 1931 through 2012, Petrified Forest National Park, AZ (WRCC 2018). For monthly and annual means, thresholds, and sums, months with five or more missing days are not considered and years with one or more missing months were not considered.

Month	Mean	High	High Year	Low	Low Year	1 Day Max	1 Day Max (dd/yyyy or mm/dd/yyyy)	>=0.01 in. (# days)	>=0.10 in. (# days)	>=0.50 in. (# days)	>= 1.00 in. (# days)
January	0.55	2.40	1993	0.00	1972	1.10	11/1941	5	2	0	0
February	.60	2.51	2005	0.00	1967	1.95	08/1991	5	2	0	0
March	0.59	2.28	1998	0.00	1947	1.47	14/1941	5	2	0	0
April	0.44	2.18	1988	0.00	1935	0.99	27/2001	3	1	0	0
May	0.41	2.82	1992	0.00	1942	1.39	05/1973	3	1	0	0
June	0.28	1.95	1988	0.00	1932	1.32	13/1955	2	1	0	0
July	1.49	5.02	2007	0.09	1993	2.54	23/1954	8	4	1	0
August	1.71	4.81	1993	0.47	1938	1.98	08/1949	9	5	1	0
September	1.19	3.94	2010	0.00	1957	2.40	29/1971	6	3	1	0
October	0.95	3.95	1972	0.00	1950	1.50	04/1968	5	3	1	0
November	0.59	2.91	1993	0.00	1932	1.31	03/1994	4	2	0	0
December	0.69	2.43	2010	0.00	1950	1.01	18/2010	5	2	0	0
Annual	9.50	15.57	1992	3.85	1950	2.54	07/23/1954	58	28	4	1
Winter[1]	1.84	5.54	1993	0.29	1959	1.95	02/08/1991	14	6	1	0
Spring[2]	1.44	4.66	1992	0.13	1950	1.47	03/14/1941	11	5	0	0
Summer[3]	3.48	6.80	2007	1.16	1960	2.54	07/23/1954	20	9	2	0
Fall[4]	2.74	6.48	1994	0.29	1945	2.40	09/29/1971	14	7	1	0

[1] Seasons are climatological not calendar seasons. Winter = Dec., Jan., and Feb.

[2] Seasons are climatological not calendar seasons.Spring = Mar., Apr., and May

[3] Seasons are climatological not calendar seasons.Summer = Jun., Jul., and Aug.

[4] Seasons are climatological not calendar seasons.Fall = Sep., Oct., and Nov.

Table 2.2-2. Snowfall records from 1931 through 2012, Petrified Forest National Park, Arizona (WRCC 2018). Table updated on Oct 31, 2012. For monthly and annual means, thresholds, and sums: months with 5 or more missing days are not considered and years with 1 or more missing months are not considered.

Month	Mean (in.)	High (in.)	Year
January	2.0	11.0	1937
February	1.2	10.0	1956
March	1.2	13.0	2006
April	0.4	6.5	1977
May	0.0	0.3	1995
June	0.0	0.0	1931
July	0.0	0.0	1932
August	0.0	0.0	1932
September	0.0	0.0	1931
October	0.1	4.0	2009
November	1.2	20.0	1931
December	2.1	21.8	1967
Annual	8.3	29.3	1967
Winter[1]	5.4	23.8	1968
Spring[2]	1.6	13.0	2006
Summer[3]	0.0	0.0	1932
Fall[4]	1.3	20.0	1931

[1] Seasons are climatological not calendar seasons. Winter = Dec., Jan., and Feb.

[2] Seasons are climatological not calendar seasons.Spring = Mar., Apr., and May

[3] Seasons are climatological not calendar seasons.Summer = Jun., Jul., and Aug.

[4] Seasons are climatological not calendar seasons.Fall = Sep., Oct., and Nov.

2.1.3. Visitation Statistics

Monthly visitation data for PEFO are available for January 1992 through July 2018 (NPS 2018a). Total number of visitors from 2008 through 2018 ranged from 543,714 (in 2008) to 836,799 (in 2014) per year with the average over the past 10 years was 664,508 (NPS 2018a).

2.2. Natural Resources

A summary of PEFO natural resources is provided here and represents an overview of the park's resources. Assessments are presented in Chapter 4.

2.2.1. Ecological Units and Watersheds

Ecological Units

Petrified Forest National Park is located in the Colorado Plateau ecoregion subunit, which encompasses the highlands of northern Arizona, southern-southeastern Utah, southwestern Colorado and northwestern New Mexico (TNC 2002). The park falls within the Arizona-New Mexico Plateau ecoregional section (TNC 2002). This section covers the southernmost 26% of the Colorado Plateau (TNC 2002). Major landforms consist of plateau, canyons, hills and valley plains with semi-desert grassland at lower elevations gradating to pinyon-juniper woodlands at higher elevations (TNC 2002).

Watershed Units

Arizona is located within the Lower Colorado Region drainage basin, which includes parts of Arizona, California, Nevada, New Mexico, and Utah (USGS 1987). This drainage basin is divided into the Little Colorado River Basin Subregion (69,671 km^2, 17,216,000 acres), the Zuni Subbasin (7,071 km^2, 1,747,200 acres), the Cebolla Creek-Rio Pescado watershed (1,273.84 km^2, 815,258 acres), and finally two subwatersheds: Togeye Lake (125.92 km^2, 31,115 acres) and Carrizozo Draw (125 km^2, 30,892 acres).

2.3. Resource Stewardship

2.3.1. Management Directives and Planning Guidance

In addition to NPS staff input, the NPS Washington (WASO) level programs guided the selection of key natural resources for this condition assessment. This included Southern Colorado Plateau Inventory and Monitoring (I&M) Network (SCPN) Program, Air Resources Division for air quality, and the Natural Sounds and Night Skies Division (NSNSD) for the soundscape and night sky sections.

Southern Colorado Plateau Inventory and Monitoring

Network In an effort to improve overall national park management through expanded use of scientific knowledge, the I&M Program was established to collect, organize, and provide natural resource data as well as information derived from data through analysis, synthesis, and modeling (NPS 2011). The primary goals of the I&M Program are to:

- Inventory the natural resources under NPS stewardship to determine their nature and status;
- Monitor park ecosystems to better understand their dynamic nature and condition and to provide reference points for comparisons with other altered environments;
- Establish natural resource inventory and monitoring as a standard practice throughout the National Park System that transcends traditional program, activity, and funding boundaries;
- Integrate natural resource inventory and monitoring information into NPS planning, management, and decision making; and,
- Share NPS accomplishments and information with other natural resource organizations and form partnerships for attaining common goals and objectives (NPS 2011).

To facilitate this effort, 270 parks with significant natural resources were organized into 32 regional networks. Petrified Forest is part of the SCPN, which includes 18 additional parks. Through a rigorous multi-year, interdisciplinary scoping process, SCPN selected a number of important physical, chemical, and/or biological elements and processes for long-term monitoring. These ecosystem elements and processes are referred to as “vital signs,” and their respective monitoring programs are intended to provide high-quality, long-term information on the status and trends of those resources.

Park Planning Reports

Natural Resource Condition Assessments

The structural framework for NRCAs is based upon, but not restricted to, the fundamental and other important values identified in a park's Foundation Document or General Management Plan. NRCAs are designed to deliver current science-based information translated into resource condition findings for a subset of a park's natural resources. The NPS State of the Park and Resource Stewardship Strategy reports rely on both information found in NRCAs as well as other sources (Figure 2.3-1).

Figure 2.3-1. Flow diagram emphasizing how information and data from both NRCAs and other sources are used in developing a resource stewardship strategy (NPS 2015).

Foundation Document

Foundation Documents describe a park's purpose and significance and identify fundamental and other important park resources and values. A Foundation Document was completed for Petrified Forest in 2015 (NPS 2015) and was used to identify some of the primary natural features throughout the park for NRCA development.

State of the Park

A State of the Park report is intended for non-technical audiences and summarizes key findings of park conditions and management issues, highlighting recent park accomplishments and activities.

NRCA condition findings are used in developing this report. Chapter 5 details a condition summary for the natural resources assessed in this NRCA.

Resource Stewardship Strategy

A Resource Stewardship Strategy (RSS) uses past and current resource conditions to identify potential management targets or objectives by developing comprehensive strategies using all available reports and data sources including NRCAs. National Parks are encouraged to develop a RSS as part of the park management planning process. Indicators of resource condition, both natural and cultural, are selected by the park. After each indicator is chosen, a target value is determined and the current condition is compared to the desired condition. A RSS has not yet commenced for the park.

2.3.2. Status of Supporting Science

Available data, reports and published papers varied depending upon the resource topic. The existing data used to assess condition of each indicator and/or to develop reference conditions are described in each of the Chapter 4 assessments. Extensive collaboration was provided by SCPN I&M, university researchers and other scientists. Additional national level programs, including Natural Sounds and Night Skies, Air Resources, and the Geologic Resources divisions were also consulted and contributed significantly to the park's condition assessments.

Chapter 3. Study Scoping and Design

Petrified Forest National Park (PEFO) Natural Resource Condition Assessment (NRCA) was coordinated by the National Park Service (NPS), Intermountain Region Office (currently known as the NPS Regional Office serving Department of Interior Regions 5, 6, 7, 8 and 9), Northern Arizona University (NAU), and the Colorado Plateau Cooperative Ecosystem Studies Unit through task agreements, P15AC00833 and P15AC00833.

The NRCA process was a collaborative effort between the Petrified Forest National Park staff, Southern Colorado Plateau Inventory and Monitoring Network staff, Intermountain Region NRCA Coordinator (Donna Shorrock, Phyllis Pineda Bovin), the NRCA team from Northern Arizona University, Flagstaff (NAU) and several subject matter experts across the intermountain west. Dr. Li-Wei Hung, Natural Sounds and Night Skies Division, Fort Collins, Colorado and Jake Holgerson, Petrified Forest National Park, Arizona (PEFO) were content matter experts for night skies. For the acoustic landscape, Kathryn Nuessly, NPS Natural Sounds and Night Skies Division, Fort Collins, Colorado, and Randy Stanley, Intermountain Region, NPS, Lakewood, Colorado, provided valuable comments and direction. Mark Meyer, National Park Service, Fort Collins, Colorado was the content matter expert for viewshed. Ksienya Taylor, National Park Service, Air Resources Division, Lakewood, Colorado, provided guidance and reviewed the air quality chapter. Hydrogeology chapter was reviewed by Dr. William Parker, PEFO. Drs. William Parker and Adam Marsh, PEFO, provided direction on the development of the paleontology and geology assessment. Kathryn Thomas, Southwest Biological Science Center, U.S. Geological Survey, Tucson, Arizona and Andy Bridges, PEFO, served as content matter experts for grasslands, riparian and alien plants assessments. Andy Bridges, PEFO, Holly Hicks, Arizona Game and Fish Department, Phoenix, Arizona, and Con Slobodchikoff, NAU, reviewed the Gunnison's prairie dog assessment. Jennifer Holmes, NAU, was the content matter expert for the grassland birds' assessment. Andy Bridges, PEFO, reviewed the bat chapter. Erika Nowak, NAU, provided expert guidance on the reptiles and amphibians assessment.

3.1 Preliminary Scoping

Preliminary scoping for PEFO began in August 2015. Dr. J. Judson Wynne submitted a draft list of natural resource topics based on the "key [natural] resources and values identified in the park's Foundation document (NPS 2015) and General Management Plan (NPS 2004). This list was then submitted to Dr. William Parker and Andy Bridges at PEFO and Donna Shorrock, National Park Service Intermountain Region. Shorrocks and Wynne then coordinated with PEFO officials to schedule the workshop and obtain all relevant reports and datasets. Park officials then compiled reports and data sets pertaining to the preliminary list of natural resources and provided these materials to Judson Wynne.

The workshop was held over a three-day period from September 02 through 04, 2015 at PEFO headquarters, Petrified Forest, Arizona. The initial list of natural resource topics was reviewed, discussed, and refined by scoping workshop attendees (William Parker and Andrew Bridges, PEFO, Donna Shorrock, NPS, Intermountain Region, and J. Judson Wynne, NAU). Through discussions, participants finalized the draft indicators, measures, and reference conditions for each resource topic.

Some topics were omitted and some key resources were identified and selected as focal resources for the condition assessment. Additional data sets and reports were identified and incorporated into the revised assessment summary (Table 3.1-1). Park staff also identified important concerns, issues/ stressors, and data gaps for each natural resource topic.

Table 3.1-1. Petrified Forest National Park (PEFO) Natural Resource Condition Assessment framework based on The Heinz Center's, *The State of the Nation's Ecosystems* (2008) report.

Level 1 Category	Level 2 Category	Focal Resources	Indicators	Measures	Threats/ Stressors	Data Gaps
I. Landscape Condition Context	–	Viewshed	Scenic Inventory Value	Scenic Inventory Value	Haze from neighboring power-plant/major metropolitan areas, sand/dust from dry washes, smoke from seasonal wildfires. Future threats potash mine and wind farm development & cell phone tower construction on adjacent private lands.	Photo-monitoring program should be established to expand upon Meyer et al. (2018). Transmissometer data should be collected to calculate visibility distances and light extinction coefficients (see Binkley et al., 1997). Periodic evaluations of historic and non-historic buildings (*sensu* Gorski and Lovato 2005) should be conducted.
			Non-contributing man-made buildings, infrastructure and other features	Extent of non-contributing man-made buildings, infrastructure, and other features	Haze from neighboring power-plant/major metropolitan areas, sand/dust from dry washes, smoke from seasonal wildfires. Future threats potash mine and wind farm development & cell phone tower construction on adjacent private lands.	Photo-monitoring program should be established to expand upon Meyer et al. (2018). Transmissometer data should be collected to calculate visibility distances and light extinction coefficients (see Binkley et al., 1997). Periodic evaluations of historic and non-historic buildings (*sensu* Gorski and Lovato 2005) should be conducted.
	–	Night Sky	Sky glow	Zenith Limiting Magnitude	Regional development, including Holbrook, Flagstaff, and Gallup; high lumen LED lights used both within park boundaries and adjacent to park.	Visual limiting magnitude measurements were taken 12 years ago.
				Bortle Dark Sky Scale	Regional development, including Holbrook, Flagstaff, and Gallup; high lumen LED lights used both within park boundaries and adjacent to park.	Visual limiting magnitude measurements were taken 12 years ago.
				Zenith Sky Brightness	Regional development, including Holbrook, Flagstaff, and Gallup; high lumen LED lights used both within park boundaries and adjacent to park.	Visual limiting magnitude measurements were taken 12 years ago.
	–	Soundscape	Sound level	Percentage of time audible	Primary source of anthropogenic noise is vehicular traffic to a lesser extent train and aircraft noise. It is likely all noise sources will increase in the future.	Additional work into effects of anthropogenic noise on wildlife is needed. Nighttime natural ambient data was not collected; these data should be collected during future monitoring efforts.

Table 3.1-1 (continued). Petrified Forest National Park (PEFO) Natural Resource Condition Assessment framework based on The Heinz Center's, *The State of the Nation's Ecosystems* (2008) report.

Level 1 Category	Level 2 Category	Focal Resources	Indicators	Measures	Threats/ Stressors	Data Gaps
I. Landscape Condition Context (continued)	–	Soundscape (continued)	Sound level (continued)	Percent reduction in listening area	Primary source of anthropogenic noise is vehicular traffic to a lesser extent train and aircraft noise. It is likely all noise sources will increase in the future.	Additional work into effects of anthropogenic noise on wildlife is needed. Nighttime natural ambient data was not collected; these data should be collected during future monitoring efforts.
				Geospatial L50 impact model	Primary source of anthropogenic noise is vehicular traffic to a lesser extent train and aircraft noise. It is likely all noise sources will increase in the future.	Additional work into effects of anthropogenic noise on wildlife is needed. Nighttime natural ambient data was not collected; these data should be collected during future monitoring efforts.
II. Supporting Environment	–	Air Quality	Visibility	Haze Index	Global climate change; increasing dust due to drier conditions; USFS prescribed burns and wildfires.	Continued monitoring of air quality indicators; monitoring of ozone-sensitive plant species.
				Human health	Global climate change; increasing dust due to drier conditions; USFS prescribed burns and wildfires.	Continued monitoring of air quality indicators; monitoring of ozone-sensitive plant species.
			Ozone	Vegetation health	Global climate change; increasing dust due to drier conditions; USFS prescribed burns and wildfires.	Continued monitoring of air quality indicators; monitoring of ozone-sensitive plant species.
			Wet Deposition	Total Nitrogen	Global climate change; increasing dust due to drier conditions; USFS prescribed burns and wildfires.	Continued monitoring of air quality indicators; monitoring of ozone-sensitive plant species.
				Total Sulfur	Global climate change; increasing dust due to drier conditions; USFS prescribed burns and wildfires.	Continued monitoring of air quality indicators; monitoring of ozone-sensitive plant species.
	–	Hydrogeology	Alluvial water quality Riparian vegetation distribution	Alluvial water quality	Quality is naturally poor.	Continued monitoring for radionuclides given both naturally occurring uranium deposits and past mining activities up slope from park.

Table 3.1-1 (continued). Petrified Forest National Park (PEFO) Natural Resource Condition Assessment framework based on The Heinz Center's, *The State of the Nation's Ecosystems* (2008) report.

Level 1 Category	Level 2 Category	Focal Resources	Indicators	Measures	Threats/ Stressors	Data Gaps
II. Supporting Environment (continued)	–	Riparian	Riparian vegetation	Native riparian composition and structure	Tamarisk is an alien species; however, the distribution is likely to change significantly due to the presence of the tamarisk beetle; although alien, this tree species provides habitat for birds and serves as a nursery tree for numerous plant species.	Cottonwood trees are not producing seeds and thus progeny for new recruitment is lacking; with the change in tamarisk distribution and no recruitment of new cottonwood trees, research is needed to address this potentially dramatic change in riparian habitat. Alternatively, a program to restore native riparian habitat should be explored. Tamarisk treatments and/ or assessments have not occurred since 2016; a monitoring/treatment program may be necessary.
				Tamarisk distribution	Tamarisk is an alien species; however, the distribution is likely to change significantly due to the presence of the tamarisk beetle; although alien, this tree species provides habitat for birds and serves as a nursery tree for numerous plant species.	Cottonwood trees are not producing seeds and thus progeny for new recruitment is lacking; with the change in tamarisk distribution and no recruitment of new cottonwood trees, research is needed to address this potentially dramatic change in riparian habitat. Alternatively, a program to restore native riparian habitat should be explored. Tamarisk treatments and/ or assessments have not occurred since 2016; a monitoring/treatment program may be necessary.
	–	Paleontology & Geology	Damage to paleontological resources	Damage to paleontological resources	Erosion will continue to damage both paleontological resources and infrastructure within and downslope from bentonite areas. Petrified wood theft will continue. Potash mining may be a future threat; however, given low market value, it is not currently a threat.	A study re-examining how to reduce petrified wood theft through conveying a greater sense of ownership and stewardship of park to visitors.

Table 3.1-1 (continued). Petrified Forest National Park (PEFO) Natural Resource Condition Assessment framework based on The Heinz Center's, *The State of the Nation's Ecosystems* (2008) report.

Level 1 Category	Level 2 Category	Focal Resources	Indicators	Measures	Threats/ Stressors	Data Gaps
II. Supporting Environment (continued)	–	Paleontology & Geology (continued)	Petrified wood theft	Petrified wood theft	Erosion will continue to damage both paleontological resources and infrastructure within and downslope from bentonite areas. Petrified wood theft will continue. Potash mining may be a future threat; however, given low market value, it is not currently a threat.	A study re-examining how to reduce petrified wood theft through conveying a greater sense of ownership and stewardship of park to visitors.
			Erosion/ Infrastructure damage in bentonite areas	Erosion/ Infrastructure damage in bentonite areas	Erosion will continue to damage both paleontological resources and infrastructure within and downslope from bentonite areas. Petrified wood theft will continue. Potash mining may be a future threat; however, given low market value, it is not currently a threat.	A study re-examining how to reduce petrified wood theft through conveying a greater sense of ownership and stewardship of park to visitors.
			Mass wasting	Mass wasting	Erosion will continue to damage both paleontological resources and infrastructure within and downslope from bentonite areas. Petrified wood theft will continue. Potash mining may be a future threat; however, given low market value, it is not currently a threat.	A study re-examining how to reduce petrified wood theft through conveying a greater sense of ownership and stewardship of park to visitors.
			Future potash extraction within and adjacent to park	Future potash extraction within and adjacent to park	Erosion will continue to damage both paleontological resources and infrastructure within and downslope from bentonite areas. Petrified wood theft will continue. Potash mining may be a future threat; however, given low market value, it is not currently a threat.	A study re-examining how to reduce petrified wood theft through conveying a greater sense of ownership and stewardship of park to visitors.
	–	Soil Biocrusts	Damage to soil biocrusts	Damage to soil biocrusts	Erosion may be greatest impact; trampling in human use areas.	No information available on occurrence and extent of soil biocrusts within park.

Table 3.1-1 (continued). Petrified Forest National Park (PEFO) Natural Resource Condition Assessment framework based on The Heinz Center's, *The State of the Nation's Ecosystems* (2008) report.

Level 1 Category	Level 2 Category	Focal Resources	Indicators	Measures	Threats/ Stressors	Data Gaps
III. Biological Integrity	Vegetation	Grasslands	Grassland Ecosystem Health	Grassland community extent	Increased drought and changing rainfall patterns (due to climate change) incongruent with grass species germination and establishment requirements; increased airborne sediment, new dune formation, and actively moving dunes; alien plant species introductions and range expansions.	Survey was limited to pre-2004 boundary. Another study in the expansion lands is needed; survey and monitoring of alien plant species.
				Native grassland species richness and composition	Increased drought and changing rainfall patterns (due to climate change) incongruent with grass species germination and establishment requirements; increased airborne sediment, new dune formation, and actively moving dunes; alien plant species introductions and range expansions.	Survey was limited to pre-2004 boundary. Another study in the expansion lands is needed; survey and monitoring of alien plant species.
				Alien plant species occurrence	Increased drought and changing rainfall patterns (due to climate change) incongruent with grass species germination and establishment requirements; increased airborne sediment, new dune formation, and actively moving dunes; alien plant species introductions and range expansions.	Survey was limited to pre-2004 boundary. Another study in the expansion lands is needed; survey and monitoring of alien plant species.
				Ratio of native to alien plant species	Increased drought and changing rainfall patterns (due to climate change) incongruent with grass species germination and establishment requirements; increased airborne sediment, new dune formation, and actively moving dunes; alien plant species introductions and range expansions.	Survey was limited to pre-2004 boundary. Another study in the expansion lands is needed; survey and monitoring of alien plant species.

Table 3.1-1 (continued). Petrified Forest National Park (PEFO) Natural Resource Condition Assessment framework based on The Heinz Center's, *The State of the Nation's Ecosystems* (2008) report.

Level 1 Category	Level 2 Category	Focal Resources	Indicators	Measures	Threats/ Stressors	Data Gaps
III. Biological Integrity (continued	Vegetation (continued)	Grasslands (continued)	Vertebrate indicator species	Grassland bird indicator species	Increased drought and changing rainfall patterns (due to climate change) incongruent with grass species germination and establishment requirements; increased airborne sediment, new dune formation, and actively moving dunes; alien plant species introductions and range expansions.	Survey was limited to pre-2004 boundary. Another study in the expansion lands is needed; survey and monitoring of alien plant species.
				Gunnison prairie dog (GPD) population size?	Increased drought and changing rainfall patterns (due to climate change) incongruent with grass species germination and establishment requirements; increased airborne sediment, new dune formation, and actively moving dunes; alien plant species introductions and range expansions.	Survey was limited to pre-2004 boundary. Another study in the expansion lands is needed; survey and monitoring of alien plant species.
				Other indicator species?	Increased drought and changing rainfall patterns (due to climate change) incongruent with grass species germination and establishment requirements; increased airborne sediment, new dune formation, and actively moving dunes; alien plant species introductions and range expansions.	Survey was limited to pre-2004 boundary. Another study in the expansion lands is needed; survey and monitoring of alien plant species.
		Alien Plants	Alteration of native plant communities	Invasiveness ranking	Drought and other disturbance events; climate change; altered soil chemistry; introduction and establishment of additional alien plant species.	No consistent alien plant monitoring for both established and newly arriving species
			Change in % cover	Change in % cover	Drought and other disturbance events; climate change; altered soil chemistry; introduction and establishment of additional alien plant species.	No consistent alien plant monitoring for both established and newly arriving species

Table 3.1-1 (continued). Petrified Forest National Park (PEFO) Natural Resource Condition Assessment framework based on The Heinz Center's, *The State of the Nation's Ecosystems* (2008) report.

Level 1 Category	Level 2 Category	Focal Resources	Indicators	Measures	Threats/ Stressors	Data Gaps
III. Biological Integrity (continued	Vegetation (continued)	Alien Plants (continued)	Distribution of alien plants	% cover of alien species in undisturbed areas	Drought and other disturbance events; climate change; altered soil chemistry; introduction and establishment of additional alien plant species.	No consistent alien plant monitoring for both established and newly arriving species
			Recovery of treated areas	% cover alien species in disturbed areas	Drought and other disturbance events; climate change; altered soil chemistry; introduction and establishment of additional alien plant species.	No consistent alien plant monitoring for both established and newly arriving species
	Wildlife	Gunnison's Prairie dog	Colony extent	Geospatial extent of active GPD colonies	Populations fluctuate due to periodic outbreaks of sylvatic plague transmission; however, park is applying pesticides to kill fleas and oral plague vaccine laced baits to help populations become more resistant	None.
			Available suitable habitat	Extent of suitable habitat within PEFO	Changes in precipitation patterns due to climate change may ultimately result in the extent of suitable habitat.	None.
		Grassland birds	Habitat	Grassland community extent	Invasive plant species and climate change (Holmes & Johnson 2013).	Grassland birds have been systematically sampled biennially since 2007.
			Species richness	Native grassland bird richness and composition	Invasive plant species and climate change (Holmes & Johnson 2013).	Grassland birds have been systematically sampled biennially since 2007.
			Indicator species	Status of indicator bird species	Invasive plant species and climate change (Holmes & Johnson 2013).	Grassland birds have been systematically sampled biennially since 2007.
		Bats	Bat species richness	Bat species richness	Increased drought conditions associated with climate change; westward advance of white-nose syndrome.	Species richness data is limited to two surveys; no studies conducted on roost habitat.
			Habitat	Summer roost habitat (maternity, bachelor and night roosts)	Increased drought conditions associated with climate change; westward advance of white-nose syndrome.	Species richness data is limited to two surveys; no studies conducted on roost habitat.

Table 3.1-1 (continued). Petrified Forest National Park (PEFO) Natural Resource Condition Assessment framework based on The Heinz Center's, *The State of the Nation's Ecosystems* (2008) report.

Level 1 Category	Level 2 Category	Focal Resources	Indicators	Measures	Threats/ Stressors	Data Gaps
III. Biological Integrity (continued	Wildlife (continued)	Bats (continued)	Habitat (continued)	Winter roosts (hibernacula)	Increased drought conditions associated with climate change; westward advance of white-nose syndrome.	Species richness data is limited to two surveys; no studies conducted on roost habitat.
		Reptiles & amphibians	Species richness	Amphibian richness	Drought and other disturbance events to standing water and edge habitats; climate change.	Limited information on amphibian and reptile species additional studies are required on aspects of distribution and phylogenetics; new study required to gauge temporal changes in species composition (last survey over 15 years old); amphibian habitat should be spatially quantified, mapped, and monitored.
				Reptile richness	Drought and other disturbance events to standing water and edge habitats; climate change.	Limited information on amphibian and reptile species additional studies are required on aspects of distribution and phylogenetics; new study required to gauge temporal changes in species composition (last survey over 15 years old); amphibian habitat should be spatially quantified, mapped, and monitored.
			Habitat	Amphibian habitat	Drought and other disturbance events to standing water and edge habitats; climate change.	Limited information on amphibian and reptile species additional studies are required on aspects of distribution and phylogenetics; new study required to gauge temporal changes in species composition (last survey over 15 years old); amphibian habitat should be spatially quantified, mapped, and monitored.

3.2 Study Design

3.2.1. Indicator Framework, Focal Study Resources and Indicators

This NRCA utilizes an assessment framework adapted from "The State of the Nation's Ecosystems 2008: Measuring the Lands, Waters, and Living Resources of the United States," by the H. John Heinz III Center for Science, Economics and the Environment. This framework was endorsed by the National NRCA Program as an appropriate framework for listing resource components, indicators/ measures, and resource conditions.

Natural Resource Condition Assessments represent an assessment of key natural resource topics identified as important to the park of interest. For PEFO's NRCA, 14 focal resources were selected for assessment (Table 3-1). Although it does not include a comprehensive list of natural resources for the park, the natural resources and processes identified were of greatest significance to park staff at the time of this effort.

Reference conditions were identified with the intent of providing a benchmark to the current condition of each indicator/ measure, which could then be compared to existing research. When a quantifiable reference for a given measure was not feasible, an attempt was made to include a qualitative reference and/ or assessment to best interpret current resource condition.

3.2.2. Reporting Areas

National Park

The primary focus of the reporting area was within PEFO's legislative boundary. However, given most natural resources don not follow geopolitical boundaries, analyses often encompassed areas beyond the park boundary.

Landscape-scale

Natural resources assessed at the landscape level included viewshed, night sky, soundscape, and hydrogeology. Viewshed data was provided by the NPS Air Resources Division. Data and reports for the night sky and soundscape assessments were provided by the NPS Natural Sounds and Night Skies Division. Guidance on the hydrogeology section was provided by PEFO natural resources staff.

3.2.3 General Approach and Methods

The general approach for developing condition assessments involves literature review and/or consulting with subject matter expert(s) for each of the focal resource topics, and when applicable, analyzing existing data to provide new interpretations for condition reporting. Following the NPS NRCA guidelines (NPS 2010b), each assessment included the following six elements:

Background and Importance

This section provides a summary on the resource, and a discussion of its relevance using existing data, publications reports, as well as descriptions developed by park staff and various planning documents.

Data and Methods

This section details the existing datasets and methodologies employed to evaluate the indicators and measures for each resource.

Reference Conditions

This section described the reference conditions used to evaluate the condition of each measure.

Condition and Trend

This section provides a discussion of the condition and trend, if available, for each indicator/measure based on each reference condition(s). Condition icons were presented in a standard format consistent with *State of the Park* reporting (NPS 2012) and serve as visual representations of condition/trend/level of confidence for each measure evaluated. Tables 3.2-1 and 3.2-2 show the condition/trend/confidence level scorecard used to describe each condition within the assessment.

Table 3.2-1. Indicator symbols used to indicate condition, trend, and confidence in the assessment.

Condition Status		Trend in Condition		Confidence in Assessment	
Condition Icon	**Condition Icon Definition**	**Trend Icon**	**Trend Icon Definition**	**Confidence Icon**	**Confidence Icon Definition**
	Resource is in Good Condition		Condition is Improving		High
	Resource warrants Moderate Concern		Condition is Unchanging		Medium
	Resource warrants Significant Concern		Condition is Deteriorating		Low

Table 3.2-2. Example indicator symbols with verbal descriptions.

Symbol Example	Verbal Description
	Resource is in good condition; its condition is improving; high confidence in the assessment.
	Condition of resource warrants moderate concern; condition is unchanging; medium confidence in the assessment.
	Condition of resource warrants significant concern; trend in condition is unknown or not applicable; low confidence in the assessment.
	Current condition is unknown or indeterminate due to inadequate data, lack of reference value(s) for comparative purposes, and/or insufficient expert knowledge to reach a more specific condition determination; trend in condition is unknown or not applicable; low confidence in the assessment.

Summary Table
Circle colors convey resource condition. Red circles signify a resource is of significant concern, yellow signify moderate condition, while green circles indicate a measure is in good condition. A circle without any color is associated with the low confidence symbol – dashed line, signifies insufficient information to make a statement about condition; therefore, condition is unknown.

Arrows within the circles indicate the indicator/ measure's trend. An upward pointing arrow represents the measure is improving, double pointing arrows denote the measure's condition is currently unchanging, and a downward pointing arrow indicates that the measure's condition is deteriorating. No arrow indicates an unknown trend.

Level of confidence ranges from high to low and is symbolized by the border around the condition circle. Bold heavy black line around the circle indicates high confidence; thin back line is indicative of medium confidence, while a dashed line signifies low confidence. Key uncertainties and resource threats are provided in the condition and trend discussion section for each resource assessment.

Sources of Expertise
Names of individuals who were consulted and/or provided a review are listed in this section, along with the writer's name that drafted the assessment.

Literature Cited
This section lists all the referenced sources for the assessment.

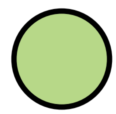
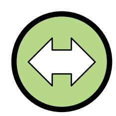
Chapter 4. Natural Resource Conditions

4.1. Viewshed

4.1.1. Condition Summary

A summary for viewshed is found below (Table 4.1-1).

Table 4.1-1. Condition assessment summary for viewshed, Petrified Forest National Park, Arizona.

Indicator	Description	Condition Status/Trend	Summary
Scenic Inventory Value	90% of the views were rated as "High" or "Very High" (Meyer et al., 2017).		Most evaluated sites (90%) received the highest score; data collected in 2017 (Meyer et al., 2017); thus, confidence high; not enough data to establish trend.
Non-contributing Man-made Buildings and Infrastructure	Historically, most structures designed to complement the landscape; all recent renovations follow recommendations by Gorski and Lovato (2005).		Gorski and Lovato (2005) provided renovation guidelines and recommendations to ensure future structures do not degrade viewshed; minimal development outside the park boundary, but PEFO has no jurisdiction concerning future development outside the park boundaries; data ~13 years old. Thus, confidence is high and trend unchanging.

4.1.2. Background and Importance

The Organic Act of 1916, which promulgated the formation of the NPS, states the NPS's mission is "to conserve the scenery…and wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." While no specific NPS-wide management policies for viewshed management and preservation exist (Johnson et al. 2008), parks are required to advance management strategies to protect scenic and viewshed quality as a fundamental natural resource. To assist parks in this effort NPS has developed a visual resource program that includes inventory and analysis tools to better inform management decisions for protecting scenic views. While not established as official policy, the program supports units throughout NPS and inventory and analysis tools are widely available.

Petrified Forest National Park is recognized for its vast Painted Desert landscapes characterized by badlands, mesas, cliffs, deeply incised canyons and rolling hills with petrified wood. Among the most popular scenic views in the park include Blue Mesa Loop, Blue Forest/Puerco River Valley, Blue Mesa Pedestal Logs, Buena Vista Point, Chinde Point, Jasper Forest Overlook, Kachina Point, and Lacey Point. The ability to experience these views offers park visitors numerous opportunities for inspiration, solitude and connecting with both past and present ecosystems.

Designated as a Class I Airshed, PEFO is afforded the highest level of air quality protection. However, viewshed protection will become increasingly challenging given the pressures of human population growth and development throughout the American West. Current concerns adversely affecting PEFO visibility include pollution-caused haze, airborne sand and dust particulate matter from dry washes during high wind events, and smoke emitted from seasonal wildfires. These pollutants and their associated documented background levels are provided in the Air Quality chapter. Additional threats that may affect the aesthetics of PEFO viewscapes include the infrastructure associated with the possible development of a potash mine, as well as the possibility of wind farms development and cell phone tower construction on lands adjacent to the park.

4.1.3. Data and Methods

Visual resource inventory adhered to the NPS methodology for assessing and protecting visual resources (NPS ARD 2018). Refer to Meyer et al. (2017) for a more thorough explanation. Data was collected 8 through 10 March 2016. The process involved photo documentation, written descriptive information about the viewpoint and viewed landscape, and the scenic quality rating for each view. These data were later examined to assign importance values to each view. Thereafter, scenic quality ratings are determined through group discussions of specific criteria, resulting in a single scenic quality value for the view (see Tables 4.1-2 and 4.1-3).

4.1.4. Reference Conditions

In March 2016, Meyer et al. (2017) conducted a visual resource inventory (VRI) at PEFO. They identified 20 popular scenic views representing a cross section of park visitor experiences and range of landscape types. Meyer et al. (2017) applied the following criteria for their evaluations: (1) *critical inventory priority* – highly valued views by either visitor experience or under immediate threat from a proposed development project or changes in land management; (2) *moderate priority* – views not likely to change in near future but may change eventually due to future land management development decisions; and, (3) *low priority* – views currently somewhat protected from visual intrusions. Using these three criteria, each view was then assessed through the lens of scenic quality and view importance. Scenic quality was scored from highest (A) to lowest (E) indicating the popular scenic views relative scenic quality. View importance was scored highest (1) to lowest (5) indicating the relative value of the view to the park and its visitors. A final scenic inventory value (SIV) was developed to provide a scoring system, which combines scenic quality and view importance into a matrix (Table 4.1-2).

Table 4.1-2. Scenic inventory value matrix ranking system with scenic quality (scored A through E; columns) and visitor importance (scored 1 through 5; rows). Overall conservation value for each vista relative to other inventoried views is classified using the matrix as very high (VH), high (H), moderate (M), low (L) or very low (VL). Refer to NPS ARD (2018).

Scenic Quality	View Importance Rating				
	1	2	3	4	5
A	VH	VH	VH	H	M
B	VH	VH	H	M	L
C	H	H	M	L	L
D	H	M	L	VL	VL
E	M	L	VL	VL	VL

4.1.5. Indicators & Measures

Indicator
Visibility

Measure
Scenic Inventory Value

The current condition for visual resources is considered "good" (Table 4.1-3) as 18 of 20 scenic views were considered "high" or "very high" (NPS ARD 2018); Table 4.1-4). View importance rating was as follows: four (1), eight (2), six (3) and two (4). Most views received high scenic quality ratings of either an "A" (10) or a "B" (9), while two views were rated as "C." Based upon these ratings, 90% of the views examined have a SIV of H or VH. At most viewpoints, visitor attention was focused on the nature features of the landscape and the multiple focal points dispersed throughout the landscape.

Identification of trends is typically not recommended by the NPS-ARD Visual Resources Program (M. Meyers, pers. comm. 2018). Currently, PEFO lacks previous inventory data to reasonably identify trends in landscape changes. PEFO may use some of the information here as baseline conditions to both monitor changes and identifying future landscape changes.

Table 4.1-3. Criteria to evaluate overall condition of visual resources based upon the best available data (NPS ARD 2018).

Category	Criteria
Good	75% or more views have a Scenic Inventory Value (SIV) of very high or high
Good/Fair	50% to 74% views have a SIV of very high or high
Fair	25% to 49% of views have a SIV of very high or high
Fair/Poor	50% to 74% of views have a SIV of moderate, low, or very low
Poor	75% or more views have a SIV of moderate, low, or very low

Regarding buildings and architectural aesthetics, most of the existing structures were designed to complement the landscape as much as possible; preservation principles to restoration of existing structures should be applied (Gorski and Lovato 2005).

Table 4.1-4. Twenty popular scenic views monitored at Petrified Forest National Park, Arizona. Scenic quality scored from “A” (highest) to “E” (lowest). View importance is ranked from 1 through 5 with 1 being highest and 5 the lowest. Scenic inventory value is categorized as very high (VH), high (H) and moderate (M; NPS ARD 2018).

View Name	Scenic Quality	View Importance	Scenic Inventory Value
Kachina Point	A	1	VH
Chinde Point	A	1	VH
Tawa Trail – Lookout Point	A	2	VH
Blue Mesa Pedestal Logs	A	2	VH
Jasper Forest Overlook	A	2	VH
Lacey Point Overlook	A	3	VH
Blue Forest/Puerco River Valley	A	3	VH
Blue Mesa Loop	A	3	VH
Buena Vista	A	3	VH
Giant Logs	B	1	VH
Tiponi Point	B	2	VH
Pintado Point	B	2	VH
Teepees	B	2	VH
Route 66	B	2	VH
Agate Bridge	B	3	H
Giant Logs Overlook	B	3	H
Puerco Valley South	B	4	M
Flattops No Name Pullout	B	4	M
Crystal Forest East	C	1	H
Newspaper Rock Overlook	C	2	H

4.1.6. Conditions and Trend

Scenic inventory value: While most of the evaluated sites (90%) received the highest score, only one year of data was collected (in 2016; Meyer et al., 2017); thus, confidence high, but there is not enough data to establish a trend.

Non-contributing man-made buildings and infrastructure: Gorski and Lovato (2005) provided renovation guidelines and recommendations to ensure future structures do not degrade the PEFO viewshed. Currently, there is minimal development outside the park boundary; however, PEFO has no jurisdiction concerning future development outside the park. As not much has changed regarding man-made buildings inside and outside the park, over the past 13 years. confidence is high with the trend identified as currently “unchanging.”

Level of Confidence

The degree of confidence varied across the two reports used to compile this assessment. The VRI inventory results were published last year (Meyer et al. 2017); thus, the level of confidence is high for these data. The condition and trends of visibility at PEFO is low as the data was over 20 years old (Binkley et al. 1997). Thus, the overall confidence in the datasets combined is medium. The maintenance guide for historic structures (Gorski and Lovato 2005) was written 13 years ago—given the age of the report, level of confidence is moderate. However, park personnel will have first-hand information that may change this score.

4.1.7. Threats, Issues, and Data Gaps

There are numerous threats to viewshed from outside the park. These include haze from neighboring power-plant and major metropolitan areas, sand/dust emitted from dry washes during high wind events, and smoke from seasonal wildfires (typically April through July). Future threats to the viewshed may include potash mine and wind farm development, and cell phone tower construction on adjacent private lands.

Management issues: Future threats to the viewshed may include general development outside park boundaries with specific potential projects that may include a potash mine, wind farm development, and cell phone tower construction on adjacent private lands. Preliminary information indicates the potash mine, if developed, would be near the western boundary of the northern section of the park. Views from locations such as Pintado Point and Lacey Point could be most affected because they are mostly free from visual intrusions. The mine could also be visible from the Route 66 viewpoint but other elements including Interstate 40 and the power line along the old Route 66 are visible.

The potential for development such as wind turbines or communication towers to be visible from popular scenic views within the park is high as many of these views span across a mostly horizontal desert landscape. Vertical elements could be highly visible depending on location and distance from popular scenic views. Final location, design and mitigation measures of these potential infrastructural features may reduce visibility within the park.

Gorski and Lovato (2005) conducted an assessment and provided recommendations for the restoration and maintenance of PEFO's historic buildings and provided guidelines for the construction of future buildings. Their goals were to maintain all historic properties and restore modified historic buildings to their original architectural design. Additionally, they recommended future buildings and infrastructure be developed in as unobtrusive manner as possible. In keeping with these recommendations and by making efforts to reduce the contrast of existing buildings and ensuring future structures are constructed in harmony with the surrounding landscape, the likelihood of a positive visitor experience will be maximized.

Interstate 40 and the Burlington Northern Santa Fe Railway traverse roughly the center of the park, while State Highway 180 contours the park's southwest and southern boundaries. While the presence of the interstate and state highway may detract from the visitor experience, the presence of roadways and associated vehicular traffic is a societal reality. Viewing trains pass through the park may be somewhat distracting, but may also contribute positively to the experience of visiting a national park in the western U.S. Both highways and railroads may be considered physical intrusions on the landscape; however, they are permanent fixtures in the park and thus any mitigation activities are unlikely.

Data Gaps

Presently, Meyer et al. (2017) completed a baseline assessment of 20 important views. Additional views could be considered for inventory to provide a comprehensive dataset for the park. In combination, these data may be used for developing a scenery management and conservation strategy. Repeat inventory should be conducted every 7 to 10 years (M. Meyer, pers. comm. 2018). Collecting data at this interval will enable PEFO to monitor change over time and adjust management strategies accordingly.

PEFO should establish a photo-monitoring program at its most important scenic views. Expanding upon the work of Meyer et al. (2017), which included the 20 most important views, a future monitoring program should include seasonal acquisition of both photographic images, as well as transmissometer measurements (Binkley et al., 1997). Transmissometer data may be used to calculate both visibility distances and light extinction coefficients (Binkley et al., 1997). These data may be used to develop a scenery management and conservation strategy.

Furthermore, periodic evaluations of historic and non-historic buildings should be conducted. These evaluations should determine whether the recommendations of Gorski and Lovato (2005) are being maintained. If not, management and maintenance of these structures should be modified to ensure these buildings are minimally obtrusive.

Finally, to comprehensively evaluate and ultimately monitor visual resources conditions, the following should be considered, which combine both VRI and threats.

- Specific popular scenic views of interest and their respective scenic quality and view importance ratings;
- Quantify potential future impacts and their implications to the visual landscapes and specific views; and,
- Identify strategies and activities to better protect the desirable visual characteristics of popular scenic views.

4.1.8. Sources of Expertise

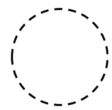
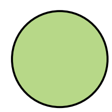
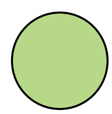
Mark Meyer, Air Resources Division, National Park Service, Fort Collins, Colorado.

4.2. Night Sky

4.2.1. Condition Summary

Condition summary for night sky provided in Table 4.2-1.

Table 4.2-1. Condition assessment summary for night skies, Petrified Forest National Park, Arizona.

Indicator	Description	Condition Status/Trend	Summary
Zenith limiting magnitude (ZLM)	Based upon 2006 data (NPS 2006b, c, d, e), ZLM was equal to or greater than 6.8 in The Pegasus region under clear skies indicating good viewing conditions (NPS 2018b).		ZLM of 6.6 is considered near pristine under average conditions; 7.0 is achievable under good observing conditions and with proper dark adaptation of the eye (Duriscoe 2015); ZLM data is 12 years old; confidence in current condition is thus low; no trend possible as only one year of data available.
Bortle sky classification	Class 3 to 4 in 2006 (NPS 2006b, c, d, e), and Class 3 to 5 in 2016 and 2017 (NPS 2018b).		Measurements were collected in 2016 and 2017; because there was only two years of data, confidence was medium and no trend is possible.
Zenith sky brightness	With the exception of two measurement sites close to the Painted Desert Visitor Center (PDVC), all sky quality meter readings, captured in 2017, exceeded 21.34 mag arcsec^{-2} (NPS 2018b).		Data captured from sky quality measurement sites collected and analyzed for 2017 only; although data quality was deemed high, because there was only one year of data, confidence was medium and no trend was possible.

4.2.2. Background and Importance

Nighttime views and environments are considered one of the critical features protected by the National Park Service (NPS 2006b; Wood 2015). Importantly, the natural photic environment, unencumbered by light pollution, is critical to ecosystem function, as well as providing both natural aesthetic and experiential qualities to park visitors (NPS 2006b; Moore et al. 2013). Underscored by the NPS Natural Sounds and Night Skies Division (NSNSD), nighttime views are distinguished both as a lightscape (the human perception of the nighttime scene, including both the night sky and the faintly illuminated terrain), and the photic environment (the totality of light at night at all wavelengths; Moore et al. 2013). The importance of dark night skies is evidenced by the fact that 31 national parks have stargazing programs; of these, the International Dark-Sky Association (IDA) has recognized 18 parks as “dark sky destinations” and many have night skies programs (NPS 2018b).

Numerous negative effects to ecological systems and human health are associated with light pollution (or artificial sky glow). Animal movements, feeding, breeding, hibernation, and even dormancy have evolved to respond to diurnal, seasonal and lunar changes in natural ambient light. For example, Hölker et al. (2010a) estimate at least 28% of all vertebrates and more than 60% of all invertebrates globally are nocturnal. Plants have also evolved to respond to varying light levels for flowering, growth, and even direction of growth (RCEP 2009; Hölker et al. 2010a). Thus, as light pollution alters the natural cycle of light and dark, natural patterns of resource use by animals and plants will likely be disrupted—negatively effecting both ecological structure and function (Gaston et al. 2013).

Humans are also negatively affected by the artificially illuminated night. Evidence suggests that prolonged exposure to light at night negatively affects sleep quality, which results in more frequent arousals, and suppressed pineal melatonin production and secretion (Cho et al. 2013). Importantly, as melatonin is an anti-carcinogenic hormone, lower levels in blood may reduce resistance to the growth of some cancers (Pauley 2004; Bullough et al. 2006; Haim et al. 2010; Garcia-Saenz et al. 2018). Thus, NPS lands with natural dark sky and proper in-park lighting can provide benefits for visitors to enjoy the natural illumination cycle.

Over the past 60 years, night skies globally have been rapidly transformed by light pollution at an approximate 6% per year increase (Smith 2009; Hölker et al. 2010b). Today, more than 80% of the planet and 99% of the human populations of U.S. and Europe persist under artificial sky glow (Falchi et al. 2016). Because of this, the importance of star filled night skies have gone from a normal occurrence to a novelty globally. Thus, for most visitors, a night sky largely absent of light pollution and illuminated by starlight enhances both solitude and the notion of wilderness.

Petrified Forest National Park remains relatively isolated from the sky glow effects of major cities. The two closest cities are Gallup, New Mexico and Flagstaff, Arizona, which are 70 and 108 miles away, respectively.

While there are several small towns adjacent to the park and their light domes do breach the horizon, currently these populated areas minimally impact the park's night sky resources. In recognition of the numerous benefits of a largely unencumbered night sky, PEFO submitted its night sky application to the IDA in March 2018 (NPS 2018c). On 21 June 2018, it was designated as a dark sky park.

4.2.3. Data and Methods

We used the most recent information produced by PEFO NPS Night Skies Team (NPS 2018c). This information was used to secure International Dark-Sky Association Silver-tier designation (NPS 2018c), which includes the following.

1) *Philosophy*: Nighttime environments have negligible to minor impacts from light pollution and other artificial light disturbance, yet still display quality night skies and have superior nighttime lightscapes.
2) *Artificial light and sky glow*: The typical observer is not distracted by close light sources and glare. Although small light domes from communities are present, typically they do not extend beyond 10–20 degrees above the horizon.
3) *Observable sky phenomena*: The full array of visible sky phenomena may be viewed. The Milky Way, faint meteors, and the zodiacal light can be seen on every clear night throughout the year.
4) *Nocturnal environment*: The area is devoid of obvious light that may disorient wildlife. Artificial light levels are identified as below the threshold of negatively impacting plant and animal

species. Ecological processes related to nocturnal habits are unaltered. There are no lights atop towers or buildings within the park boundary.

5) *Visual limiting magnitude*: Equal or greater than 6.8 under clear skies and good seeing conditions. In 2006, the NPS Night Skies Team measured Limiting Magnitudes of 6.8 and 6.9 in The Pegasus region (NPS 2006b, c, d, e).
6) *Bortle sky classification*: 3–5. The NPS Night Skies Team identified Bortle Class ratings ranging from 3 to 4 in 2006. Park staff observed Bortle Class ratings ranging from 3 to 5 in 2016 and 2017.
7) *Sky quality meter readings*: >21.34. Except for two measurement sites close to the Painted Desert Visitor Center (PDVC), all SQM reading averages exceeded 21.34.

Additionally, while the artificial sky brightness interactive map of Falchi et al. (2016; Figure 4.2-1) and CIRES (2018) differs slightly from the findings of the PEFO NPS Night Skies Team, it is still useful as a tool to highlight the current and future impediments in maintaining unencumbered night skies (Figure 4.2-2).

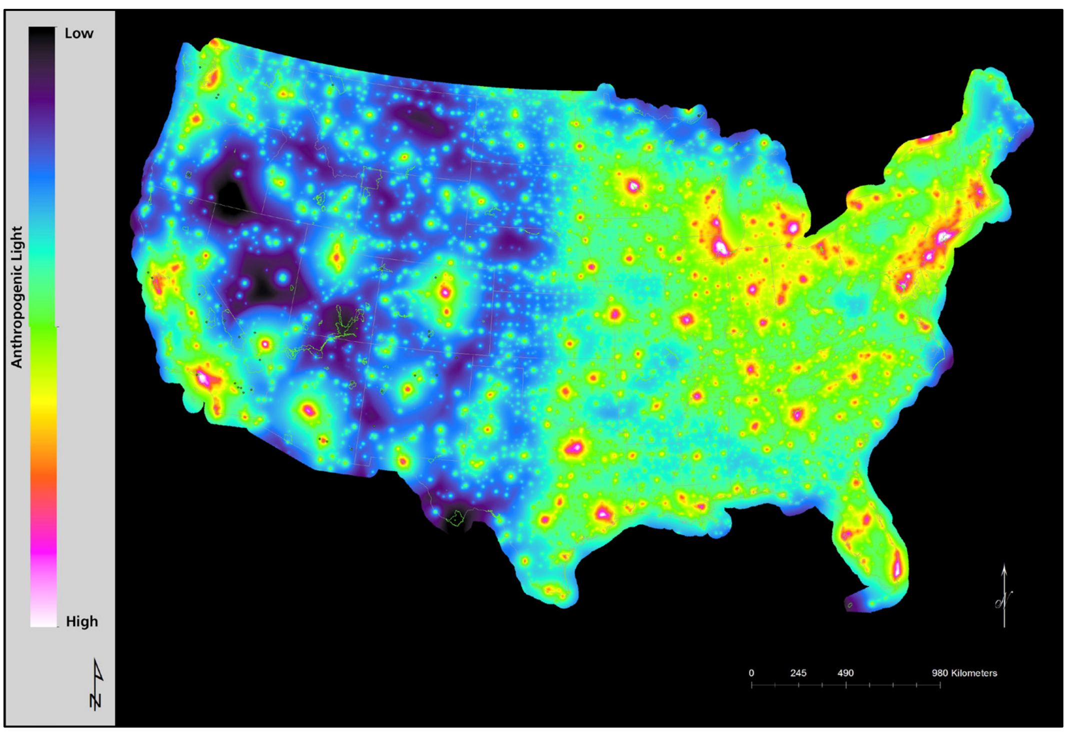


Figure 4.2-1. Artificial sky brightness map of the United States based upon Falchi et al. (2016) and CIRES (2018).

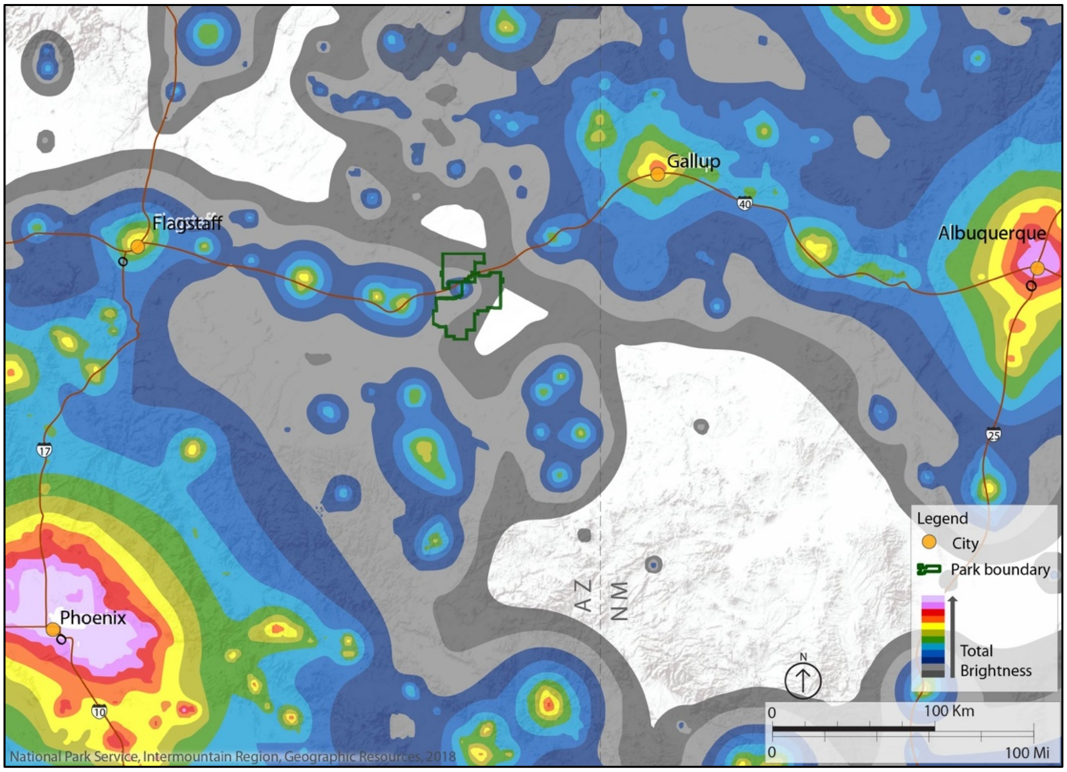


Figure 4.2-2. Regional view of anthropogenic light surrounding PEFO based upon Falchi et al. (2016) and CIRES (2018).

4.2.4. Indicators & Measures

Indicator
Sky glow

Measure
Zenith Limiting Magnitude

Zenith limiting magnitude (ZLM), or the faintest stars than can be observed visually without optical aid (naked eye) near the zenith, or darkest part of the sky (Duriscoe 2015). A ZLM of 6.6 is considered near pristine under average conditions, while 7.0 is achievable under good observing conditions and with proper dark adaptation of the eye; a number lower than 6.3 usually indicates significantly degraded sky quality (Duriscoe 2015). Based upon 2006 data (NPS 2006b, c, d, e), PEFO ZLM is equal to or greater than 6.8 in The Pegasus region under clear skies indicating good seeing conditions (NPS 2018c).

Indicator
Sky glow

Measure
Bortle Sky Classification

The Bortle Dark Sky scale was developed to evaluate the quality of the night sky for stargazing (refer to Appendix A, Bortle 2001). Consisting of nine classes, this scale uses a number of objects observable at night including zodiacal light, gegenschein, zodiacal band, and galaxy M33 to assign a class rating to a given area (Bortle 2001). Using this system, the NPS Night Skies Team rated PEFO's night skies from Class 3 to 4 in 2006 (NPS 2006b, c, d, e) and Class 3 to 5 in 2016 and 2017 (NPS 2018c). These classifications range from rural skies (Class 3) to suburban skies (Class 5; Bortle 2001).

Indicator
Sky glow

Measure
Zenith Sky Brightness

Zenith Sky Brightness was measured with a Unihedron Sky Quality Meter, which was aimed at the zenith, measures the brightness of the sky, and captured data in magnitudes per square arc-second (mag arcsec^{-2}; Duriscoe 2015). With the exception of two measurement sites close to the Painted Desert Visitor Center (PDVC), all sky quality meter readings, captured in 2017, exceeded 21.34 mag arcsec^{-2} (NPS 2018c).

4.2.5. Reference Conditions

Ideally, the reference condition would be a night sky unimpeded by anthropogenic skyglow. However, given that PEFO's night sky met the requirements for becoming a dark sky park, this should be the new baseline that the park should strive to retain.

4.2.6. Conditions and Trend

The current condition for night skies is considered "good" with a trend of "unknown" and likely to be "changing" (Table 4.2-1). Currently, PEFO maintains the top third and fourth darkest categories on the Bortal (2001) sky brightness scale. Subsequently, PEFO was recognized as a "dark sky destination" by IDA (J. Holgerson, pers. com. 2018). Due to burgeoning metropolitan areas (i.e., Phoenix, Arizona and Albuquerque, New Mexico), growing smaller cities (i.e., Gallup, New Mexico and Flagstaff, Arizona), and expanding townships, the issues listed below are expected to adversely impact PEFO's dark sky character. Figure 4.2-3 is 360° panorama depicting total sky brightness in false colors; this image illustrates nearby light domes and other sources of natural and anthropogenic light.

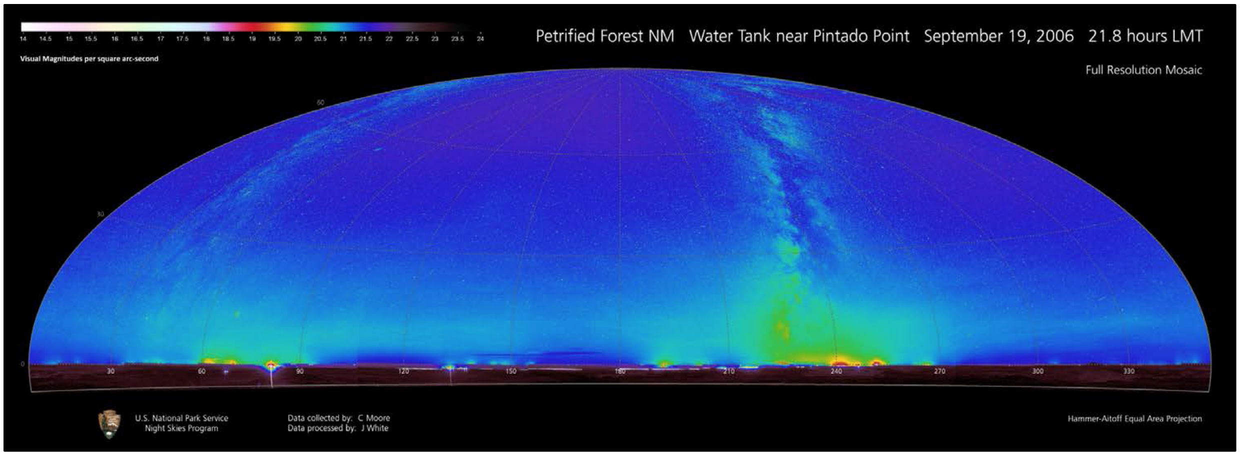


Figure 4.2-3. 360° Panoramic image of natural and anthropogenic light sources, water tank at Pintado Point, Petrified Forest National Monument, Arizona, 19 September 2006 (NPS 2018c).

4.2.7. Threats, Issues, and Data Gaps

Issues

The growing population centers of Phoenix, Flagstaff, Gallup and Albuquerque may ultimately impinge upon the dark sky rating of PEFO. With perhaps the exception of Flagstaff, Arizona, which is recognized as the world's first international dark skies city (FDSC 2018), the other regional metropolitan areas have not addressed their light pollution emissions. Additionally, the low expense, and energy efficiency of most LED lighting has made these bulbs quite attractive for outdoor lighting. Unfortunately, LED lights are often high lumens, which can contribute significantly to light pollution (Falchi et al. 2011) in rural communities surrounding PEFO, thus contributing to artificial sky glow and impacting optimal dark sky conditions.

To reduce the impacts of LED lighting, we recommend the following sustainable outdoor lighting principles: (i) light only if needed, and only when needed; (ii) light only where it is needed; (iii) use warm-white or amber light; (iv) use the minimum amount of light needed; and, (v) use energy-efficient and lights (NPS 2016).

Data Gaps

Petrified Forest National Park was recently designated as a dark sky park (J. Holgerson, pers. com. 2018). Data used to designate the park include: visual limiting magnitude measurements were taken in 2006, Bortle Sky classifications were documented in 2016 and 2017, and zenith sky brightness sky quality metrics were collected in 2017 (NPS 2018c). As visual limiting magnitude measurements are over 12 years old, this is considered to be a data gap. Thus, the overall confidence in this dataset is "medium."

4.2.8. Sources of Expertise

- Li-Wei Hung, Natural Sounds and Night Skies Division, Fort Collins, Colorado
- Jake Holgerson, Petrified Forest National Park, Petrified Forest, Arizona

4.3. Acoustic Environment

4.3.1. Condition Summary

Condition summary of acoustic environment provided in Table 4.3-1.

Table 4.3-1. Condition assessment summary of acoustic environment, Petrified Forest National Park, Arizona.

Indicator	Description	Condition Status/Trend	Summary
Percent time audible (human noise)	Backcountry site 38.3% and 22.9% for summer and winter, while front-country site was 84% and 51.5% for summer and winter, respectively (Lee and MacDonald 2011).		Below 35% is considered a “good” reference condition (NPS 2014, Lynch et al. 2011); no moderate and significant concern levels have been established by NPS. Based upon the data collected, only the backcounty site during winter (22.9%) was considered in “good” condition; all other measurements exceeded this value. Because data were collected only twice, once during late summer (2004) for ~16 days and again in late winter (2010 for ~28 days, establishing trends were not possible. Data were collected between 8 and 14 years ago; thus, confidence is low.
Percent reduction in listening area (difference between human-caused and natural ambient sounds)	Summer backcountry conditions (4.3 dB), while winter backcountry conditions were 2.1 dB. For the front-country, summer measurements were 7.3 dB and winter was 5.2 dB.		Summer backcountry conditions (4.3 dB at >60% reduction in listening area), the condition was of “significant concern,” while winter backcountry conditions were “moderate” (2.1 dB at ~37% reduction in listening area). For the front-country, conditions for both summer (7.3 dB at ~80% reduction) and winter (5.2 dB at 68%) are of “significant concern” (Lee and MacDonald 2011). No trends possible due to limited data. Data were collected 8 to 14 years ago (see justification above); thus, confidence is low.
Geospatial sound model (LA_{50} impact)	Mean impact modeled at 3 decibels (dBA); ranges from 2 dBA in areas with the least impact to 10 dBA in areas with more impact (Mennitt et al. 2014).		Mean impact value (3 dB) is ranked as “moderate,” The NPS (2014) considers ≤ 1.5 dB as “good,” >1.5 and ≤ 3.0 dB as “moderate” and >3.0 dB as “significant concern.” Thus, the condition ranges from “moderate” to “significant concern.” Given the nature of the dataset, no tread was possible. As the models use data seven to 18 years old, confidence is low.

4.3.2. Background and Importance

The natural soundscape (or acoustic environment) 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 acoustic environment and restore it, when degraded, to the natural condition wherever possible. Additionally, NPS is required to prevent or minimize degradation of the natural acoustic environment from noise (i.e., inappropriate/undesirable human-caused sound). Although the management policies currently refer to the term *soundscape* as "the totality of the perceived acoustical environment" (Turina et al. 2013) that occur in a park, it may be further described as the total amount of ambient noise in an area, measured in terms of frequency and amplitude (decibels; Ambrose and Burson 2004). From a management perspective, acoustic environment is a combination of both what humans and other species may aurally perceive. The physical sound resources (i.e., 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*.

The NPS has been working for several decades to establish baseline conditions, as well as to develop measuring and monitoring methods for acoustic environments in national parks (Miller 2008). Their efforts have been geared towards both visitor experiences (Rogers and Sovick 2001; Sovick 2001; Miller 2008; Lynch et al. 2011) with relatively few studies examining the impacts of anthropogenic noise on wildlife populations on NPS lands (Barber et al. 2011; Brown et al. 2012; Francis and Barber 2013; Buxton et al. 2017). Studies have shown the negative impacts of human-generated noise on birds (Dooling and Popper 2007; Habib et al. 2007; Slabbekoorn and Ripmeester 2008; Francis et al. 2009; Francis et al. 2011a), bats (Schaub et al. 2008), rodents (Shier et al. 2012), frogs (Barber et al. 2010; Bee and Swanson 2007), and invertebrates (Morley et al. 2014).

Roads and energy development facilities appear to have the greatest impacts on wildlife (as opposed to inputs such as overflights; Barber et al. 2011; Newman et al. 2014). Road noise can alter animal behavior, movement patterns, ability to find prey, and breeding processes (Reijnen and Foppen 2006; Bee and Swanson 2007; Barber et al. 2011; Siemers and Schaub 2011), while noises associated with energy development are often incessant and have been associated with increased levels of chronic stress on animals near these sites (Bayne et al. 2008; Barber et al. 2009; Francis et al. 2011b; Blickley et al. 2012; Souther et al. 2014). Some species are capable of adapting to long-term anthropogenic noise sources in their environment, while others cannot (Barber et al. 2010). Research further suggests that due to the complex nature of sounds and that impacts at individual and population scales may affect organisms at the ecosystem and process levels, ambient and pulsed noise levels perceived by wildlife should be examined and addressed at multiple spatial and temporal scales (Slabbekoorn and Halfwerk 2009; Barber et al. 2011; Dumyahn and Pijanowski 2011a, 2011b). For example, an increase of 4 decibels (dB) in the median background sound pressure level represents a reduction in listening area for wildlife and visitors of 60% (Wood 2015). If a predator can hear a potential prey animal in an area of 100 square feet in a setting with natural ambient sounds, that animal's ability to hear would be reduced to 40 square feet if the median background sound pressure level was increased by 4 dB. Park visitors would experience similar reductions in their ability to hear natural sounds, which would affect their experience at the park.

Aircraft noise intrusions include air tour (fixed wing aircraft and helicopters), commercial general aviation, military, and other aircraft sounds (NPS 2018d). These acoustic disruptions are linked to negative health effects on humans (Morrell et al. 1997; Hygge et al. 2002; Jarup et al. 2008). Additionally, aircraft overflights disturb behavior and alter time budgets of harlequin ducks (*Histrionicus histrionicus*; Goudie 2006) and mountain goats (*Oreamnos americanus*; Goldstein et al. 2005), while aircraft noise simulations evoked escape behaviors of nesting bridled (*Sterna anaethetus*) and crested (*S. bergii*) terns (Brown 1990).

Additional substantial impacts to wildlife may occur when anthropogenic noise may impede an animal's ability to perceive a natural sound. For example, each 3 dB increase in the background sound pressure level results in a reduction of the listening area by one-half (Barber et al. 2010). Furthermore, masking can impede animal communication, reproductive and territorial advertisement, and acoustic location of prey or predators (Barber et al. 2010). Because anthropogenic noise can mask predator sounds, it is perhaps most detrimental to prey species (Landon et al. 2003; Chan et al. 2010; Brown et al. 2012). However, masking of natural sound is not limited to wildlife. This may adversely impact human communication and may impede visitor detection of wildlife sounds.

In general, based upon surveys of the American public, the sounds of nature are considered an important reason for visiting national parks (NPS 2014; Wood 2015). 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). Despite this desire for quiet environments, anthropogenic noise continues to intrude upon natural areas and has become a source of concern in national parks (Lynch et al. 2011).

Numerous parks have developed enabling legislation or current planning documents to include protection the natural acoustic environment. Examples on NPS lands in the western U.S. include Grand Canyon National Park Enlargement Act of 1975, Zion National Park general management plan, and Glacier National Park general management plan (Jensen and Thompson 2004). Safeguarding the natural acoustic environment at PEFO, when and where possible, may both enhance visitor experience and provide additional benefits for interpretive programs on the park's resources (Wood 2015).

At PEFO, anthropogenic noise included primarily visitor-related events such as occasional aircraft, train, and Interstate 40 sounds (Lee and MacDonald 2011). Human sounds are also audible in the backcountry; however, natural sounds predominate (Lee and MacDonald 2011). The remote settings throughout most of the park, as well as the diverse flora and fauna will benefit from preservation of natural sounds and anthropogenic noise mitigation (Wood 2015).

4.3.3. Data and Methods

Acoustic monitoring was conducted at PEFO to estimate natural ambient sound levels and identify all audible anthropogenic sound sources (Lee and MacDonald 2011). Continuous, one-second, A-weighted sound levels and their associated one-third octave-band un-weighted spectrum from 20 to 20,000 Hz acoustic data were collected. Data were collected from 0700 to 1900 hr for 16 and 15 days during summer (September 2004), and 26 and 28 days during winter (March 2010) for front- and back-country sites, respectively. This was done to compare and contrast anthropogenic noise between the front- and back-country.

To calculate the percent time audible metric, a measure that calculates the percent of time human-caused sound was audible to the human ear, we used the reported percentage of all aircraft and other audible human noise that was audible for both summer and winter. For a general measure representative of broad changes that can account for the reduction in listening area, we used the LA_{50} metric for existing ambient (which represents anthropogenic noise) and natural ambient sound levels. This metric represents the sound level that was exceeded 50 percent of the day. For example, for a dataset representing 100 samples (or data points) within a measurement period, the samples are sorted from highest sound level to lowest sound level with the 50^{th} sound-level (or the median) representing the 50-percentile that exceeded the natural sound level.

In general, and as expected, the backcountry was characterized by less anthropogenic noise than the front-county. At the backcountry monitoring site, sound was primarily natural (wind gusts through vegetation) but included aircraft-related and distant Interstate 40 traffic noise with the occasional train-related sounds (Lee and MacDonald 2011). The front-country monitoring site was characterized primarily by visitor-related noise (vehicles on the Administrative Road and the parking lot, and voices). The occasional aircraft and train-related sounds were also audible (Lee and MacDonald 2011).

There is a maximum of 60 tours permitted each year to fly over the park. Currently, three operators hold interim operating authority (IOA, the annual limit of tours) from the FAA to conduct commercial tours. The number of air tours ranged from six to 22 per year over the past five years (Lignell 2018; Table 4.3-2).

Table 4.3-2. Summary of commercial aircraft tours per year operating over Petrified Forest National Park from 2013–2017 (Lignell 2018).

Year	Number of Tours
2013	14
2014	20
2015	22
2016	8
2017	6

The NPS Natural Sounds and Night Skies Division (NSNSD) predicted anthropogenic noise impacts at the landscape scale using the geospatial sound (LA_{50} Impact) model developed by Mennitt et al. (2014). This geospatial sound model predicts A-weighted median sound levels (LA_{50}) to represent average listening conditions, which was based on summer daytime (0700–1900 hr) A weighted 1 second sound level measurements. The difference between predicted existing and predicted natural sound levels provides a measure of how much anthropogenic noise is increasing the existing sound level above the natural sound level. Sound pressure levels for the continental United States were predicted using empirical acoustic measurements combined with explanatory variables including location, climate, land cover, hydrology, wind speed, and proximity to noise sources (roads, railroads, and airports). Predictions were made for daytime impacts during midsummer. Impacts were determined by taking the difference between the "existing" (including anthropogenic noise) and "natural" ambient sounds levels (both variables were predicted by the model). The model employed a 270-meter pixel resolution. Levels in national parks may vary greatly, depending on location, topography, vegetation, biological activity, weather conditions and other factors. For example, the din of a typical suburban area fluctuates between 50 and 60 dB, while the crater of Haleakala National Park is intensely quiet, with levels around 10 dB (Wood 2015). To examine the variation of anthropogenic noise at PEFO, a park-specific impact map was generated from this national geospatial model.

4.3.4. Indicators & Measures

Indicator
Level of anthropogenic noise (metric directly measured)
Measures
Percentage of time audible

Based upon data from 89 acoustic monitoring sites, the median percent time audible of anthropogenic noise during daytime hours was 35% (NPS 2014; Lynch et al. 2011); however, the data and median percent time audible does not differentiate between urban and non-urban national parks. We used the value provided by Interim NRCA Guidance Acoustic Environment document (NPS 2014) as the reference condition for "good" if it was ≤ 35%; Table 4.3-3). Moderate and significant concern conditions have not been examined or established by the NPS (K. Nuessly, pers. com. 2018); thus, this indicator was not assessed.

Using data from PEFO acoustic monitoring sites (in situ and office listening combined), percent of time audible for anthropogenic noise at the backcountry site was 38.3% and 22.9% for summer and winter; for the front-country site, it was 84% and 51.5% for summer and winter (Lee and MacDonald 2011; Table 4.3-4).

Table 4.3-3. Reference conditions used to assess measures of sound levels, Petrified Forest National Park, Arizona. Reference conditions for percent reduction in listening area and geospatial (LA_{50} impact) model (NPS 2014).

Indicator	Measure	Good	Moderate	Significant Concern
Sound Pressure Level	% time audible	≤35%	Not established	Not established
	% reduction in listening area (non-urban parks)	Reduced by ≤30% Difference between sound pressure levels is ≤ 1.5)	Reduced by 30-50% (Difference between sound pressure levels is >1.5 and ≤ 3.0)	Reduced by > 50% (Difference between sound pressure levels is >3.0)
	Geospatial (LA_{50} impact) model, non-urban parks (Mean LA_{50} impact)	Listening area reduced by ≤30% (Difference between sound pressure levels is ≤ 1.5 dB)	Listening area reduced by 30–50% (Difference between sound pressure levels is >1.5 and ≤ 3.0 dB)	Listening area reduced by > 50% (Difference between sound pressure levels is >3.0 dB)

Table 4.3-4. Summary of acoustic observer log data (in situ and office listening combined) for back- and front-country sites for summer (September 2004) and winter (March 2010) monitoring periods for daytime hours (0700 to 1900 hrs), Petrified Forest National Park, Arizona (Lee and MacDonald 2011).

Acoustic Zone	Season	Visitor Use	% Time Audible (Human)	% Time Audible (Natural)
Backcountry	Summer	Low	38.3	61.7
	Winter	Low	22.9	77.1
Frontcountry	Summer	High	84	16
	Winter	High	51.5	48.5

Indicator

Level of anthropogenic noise (metric directly measured)

Measures

Percentage reduction in listening area

Listening area is the defined as the area within which an animal may perceive sound. Reduction in listening area quantifies the loss of hearing ability to humans and wildlife as a result of an increase in ambient noise level. Under natural ambient conditions a sound is audible within a certain area around visitors or wildlife. If the background sound pressure level is increased due to a noise event, the area in which the sound is audible decreases. The reduction in listening area is calculated from difference between existing ambient levels (i.e., anthropogenic noise) and natural ambient levels (which exclude anthropogenic sound; NPS 2014). Barber et al. (2010) quantified these effects and found that seemingly small increases in sound level can have substantial impacts in terms of loss of listening area. We can determine the percentage reduction in listening area from the difference between natural and existing ambient (Barber et al. 2009). The estimated decreases in listening area due to an increase in background sound levels are summarized in Table 4.3-5.

Table 4.3-5. Increases in background sound pressure level at one decibel (dB) increments with resultant decreases in listening area (NPS 2014).

Increase in background sound pressure level (dB)	Decrease in listening area
1	21%
2	37%
3	50%
4	60%
5	68%
6	75%
7	80%
8	84%
9	87%
10	90%

NPS (2014) ranks impact conditions of >1.5 to ≤ 3.0 dB (with a reduction in listening area between 30 and 50%) as "moderate," while values of >3 dB (with a reduction in listening area by > 50%) are categorized as a "significant concern" condition. Thus, the average sound impact value (3 dB) is ranked as "moderate," while the minimum (2 dB) and maximum (11 dB) impact values range from "moderate" to "significant concern" (Table 4.3-3).

For PEFO, the difference between the existing and natural ambient (LA_{50}) for summer backcountry conditions was 4.3 dB (a >60% reduction in listening area) and is considered of "significant concern." For winter backcountry conditions, the difference between the existing and natural ambient (LA_{50}) was 2.1 dB, resulting in a ~37% reduction in listening area and was assigned a "moderate" condition. For the front-country, both summer (7.3 dB difference at ~80% reduction) and winter (5.2 dB difference at 68%) are of "significant concern." Table 4.3-6 summarizes these data.

Table 4.3-6. Existing ambient daytime, natural ambient daytime and percent reduction in listening area for back- and front-country sites for summer (September 2004) and winter (March 2010) monitoring periods, Petrified Forest National Park, Arizona (Lee and MacDonald 2011).

Acoustic Zone	Season	Existing Ambient Daytime LA_{50} (dB)	Natural Ambient Daytime LA_{50} (dB)	% Reduction in Listening Area
Backcountry	Summer	24.1	19.8	60
	Winter	21.0	18.9	37
Frontcountry	Summer	27.4	20.1	80
	Winter	24.9	19.7	68

Indicator
Level of anthropogenic noise (predicted by model)

Measures:
Geospatial Sound Model (LA_{50} Impact)

We use the geospatial sound model to provide us with a spatial understanding of natural and existing ambient in the park. The limitations of the monitoring data are that they provide us with an extrapolation of noise levels across the entire park based upon point-specific data.

In addition to predicting the median natural and ambient sound levels, the model also calculates the difference between the two metrics, providing a measure of impact to the acoustic environment from anthropogenic sources. The resulting metric (L_{50} dBA impact, Figure 4.3-1) indicates how much anthropogenic noise raises the existing sound pressure levels in a given location. The average impact sound level in PEFO was 3 dB above natural conditions; values ranged from 2 dB in the least impacted areas to 11 dB in the most impacted areas (Table 4.3-7). Figure 4.3-1 provides the spatial representation of modeled median impact sound levels in the park. Maps for existing and natural acoustic environment condition maps are provided in Appendix B.

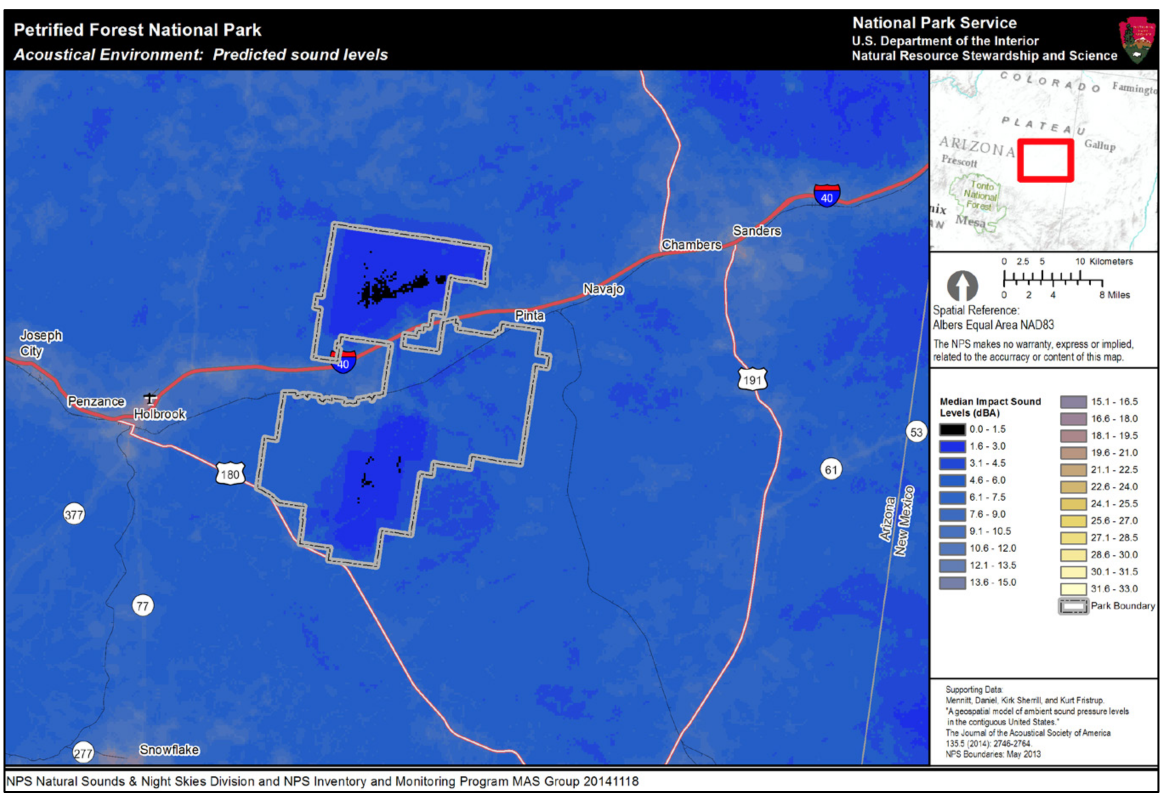


Figure 4.3-1. Median sound level impact map generated by the LA50 dB impact map using version 3.0 of the geospatial model, Petrified Forest National Park, Arizona (Mennitt et al. 2014). Color scale indicates how much anthropogenic noise raises the existing sound levels in a given location (measured in A-weighted decibels, or dB). Black and dark blue colors indicate low impacts while gradating to lighter colors (lighter blue through light yellow) indicate greater impacts.

Table 4.3-7. Minimum, maximum, and median values of modeled LA_{50} measurements, Petrified Forest National Park, Arizona. Data summary provided by Kathryn Nuessly, NPS-NSNSD.

Acoustic Environment Condition	LA_{50} values (dB)		
	Minimum	Maximum	Mean
Natural	22	24	23
Existing	24	34	26
Impact	2	10	3

4.3.5. Reference Conditions

Reference conditions 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 (NPS 2014). Various characteristics may be used to gauge how anthropogenic noise affects the acoustic environment including rate of occurrence, duration, amplitude, pitch, and whether the sound occurs consistently or sporadically. To capture these characteristics, 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.

In cases where on-site measurements have not been gathered or are limited, one may reference meta-analyses of national park monitoring efforts such as those detailed in Mennitt et al. (2014). The mean LA_{50} impact model compiled data from 291 park monitoring sites across the U.S. and is at least four years old. Because this is a continental model, scale is 270 m resolution. Through this effort, Mennitt et al. (2014) revealed the median daytime existing sound level in national parks is ~31 dB (NPS 2014). NPS (2014) provided further interim guidance for interpretations of this model, which consist of values of ≤ 1.5 dB as representing a "good" condition, between >1.5 and ≤ 3.0 as "moderate," and >3.0 dB as "significant concern."

At PEFO, mean impact is predicted to be 3 decibels (dBA) and ranges from 2 dBA in areas with the least impact to 11 dBA in areas with more impact (Mennitt et al. 2014; Wood 2015). Thus, the existing sound level (with the influence of man-made sounds) is predicted to be 3 decibels above the natural ambient sound level.

4.3.6. Conditions and Trend

Overall Condition and Trend

The 2004/2005 and 2011 data indicated that, for the sites monitored, the main source of anthropogenic sound was vehicle/roadway traffic and to a lesser extent aircraft overflights and trains (Lee and MacDonald 2011). According to Burlington Northern and Santa Fe Railway, the number of trains averaged 87 per day (over a 24-hour period) in 2004, and 72 trains per day in 2010 with a speed of approximately 40 mph (64.4 kph; Lee and MacDonald 2011); whether train traffic will increase in the future is uncertain, but is likely to remain constant. Other sources are likely to either increase or remain constant over time. Therefore, the overall trend is either unchanging or declining.

Level of Confidence

Given the limitations of the PEFO acoustic dataset, the conditions of two metrics were assessed (percent time audible and percent reduction in listening area). As an additional measure, the PEFO portion of the national geospatial (LA_{50} impact) model (Mennitt et al. 2014) was examined.

Confidence in the quality of the data is rated at low for following reasons. Acoustic monitoring data ranges from 14 years old for summer (collected in September 2004) to over eight years old for winter (collected March 2010). Without current data, it is left to conjecture whether anthropogenic noise has increased or diminished. Second, the assessments for percent reduction in listening area were limited to daylight hours because nighttime natural ambient data was not collected (refer to Lee and MacDonald 2011). Thus, for both metrics, sufficient data are lacking to conduct a high confidence assessment of the acoustic environment. Given that most of the anthropogenic noise was attributed to vehicular traffic (Lee and MacDonald 2011) and vehicular traffic is diminished considerably during nighttime hours, anthropogenic noise will likely be lower when compared to daylight hours.

4.3.7. Threats, Issues, and Data Gaps

Emerging Issues

A common source of noise in national parks is transportation (i.e., airplanes, vehicles). Growth in transportation is increasing faster than is the human population (Barber et al. 2010). Between May 1993 and May 2018, traffic on U.S. roadways increased by 29.44 % from 2,269,835 to 3,216,841 vehicle miles (US DOT 2018). Commercial air tours have fluctuated over the past five years; however, as park visitation increases this may also result in a larger number of air tours. 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).

Data Gaps

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 (NPS 2015). Several recommendations have been made for human exposure to noise, but no guidelines exist for wildlife and the habitats shared with humans. Rapoza et al. (2008) and McKenna et al. (2016) developed and revised a framework to access impacts associated with aircraft noise; this framework should be examined for its applicability at PEFO. 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 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 (NPS 2015).

Additionally, because nighttime natural ambient data was not collected, the assessments for percent time audible (anthropogenic noise) and percent reduction in listening area were limited to daylight hours (Lee and MacDonald 2011). Future acoustic monitoring work should include both daytime and nighttime natural ambient measurements.

4.3.8. Sources of Expertise

Kathryn Nuessly, NPS Natural Sounds and Night Skies Division, Fort Collins, Colorado provided guidance in selecting the measures to access and reviewed this document. Randy Stanley, Intermountain Region, NPS, Lakewood, Colorado also provided valuable comments leading to the improvement of this chapter. Additionally, NSNSD scientists aid NPS park units in managing anthropogenic sounds to best address the various expectations of visitors. They provide technical assistance to parks in the form of acoustic monitoring, data collection and analysis, and in developing acoustical baselines for planning and reporting purposes. For more information, go to http://nps.gov/nsnsd.

4.4. Air Quality

4.4.1. Condition Summary

Condition summary for air quality provided in Table 4.4-1.

Table 4.4-1. Condition assessment summary for air quality, Petrified Forest National Park, Arizona.

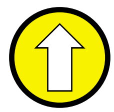
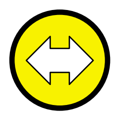
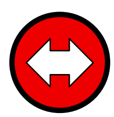
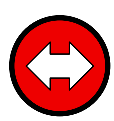
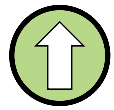
Indicator	Description	Condition Status/Trend	Summary
Haze	For 2006–2015, visibility improved on the 20% clearest days and on the 20% haziest days (IMPROVE Monitor ID: PEFO1, AZ).		Natural visibility conditions are those that would exist in a given area in the absence of human-caused visibility impairment. Estimated annual average natural condition on mid-range days equals 2.9 deciviews (dv) at PEFO. “Moderate concern” based on NPS (2018g) and the 2011–2015 estimated visibility on mid-range days of 4.1 deciviews (dv). Overall trend is improving. As the data has been collected for over a decade, confidence is high.
Ozone	For 2006–2015, ozone concentration remained relatively unchanged (AQS Monitor ID: 040170119, AZ). Status based on NPS (2018g) and the 2011–2015 estimated ozone of 69.1 parts per billion (ppb).		With ground-level ozone at 69.1 parts per billion (ppb), human health risk warrants “moderate concern.” Over the 2006–2015 monitoring period, trend is “unchanged” and confidence is “high” with the long-term dataset.
Vegetation Health	Vegetation health based on 3-month maximum (12hr W126). Status based on NPS (2018g) and the 2011–2015 estimated the W126 metric at 15.5 parts per million-hours (ppm-hrs).		Vegetation health risk from ground-level ozone levels warrants “significant” concern. However, risk assessment concluded that plants were at moderate risk for ozone damage (Kohut 2007). For 2006–2015, W126 remained relatively “unchanged” (AQS Monitor ID: 040170119, AZ). Confidence level justification same as above.
Wet deposition of Nitrogen	Status based on NPS (2018h) and the 2011–2015 estimated wet nitrogen deposition of 1.3 kilograms per hectare per year (kg/ha/yr).		Nitrogen deposition may disrupt soil nutrient cycling and affect biodiversity of some plant communities including arid and semi-arid and grassland. Estimated wet nitrogen deposition of 1.3 kilograms per hectare per year (kg/ha/yr) between 2011 and 2015 (NPS 2018h), which warrants “moderate” concern with trend of “unchanged” over the monitoring period. Given the duration of the dataset, confidence is “high.”

Table 4.4-1 (continued). Condition assessment summary for air quality, Petrified Forest National Park, Arizona.

Indicator	Description	Condition Status/Trend	Summary
Wet deposition of Sulfur	Status based on NPS (2018g) and the 2011–2015 estimated wet sulfur deposition of 0.5 kilograms per hectare per year (kg/ha/yr).		Acidification effects may include changes in water and soil chemistry that impact ecosystem health. Wet sulfur deposition is in "good" condition. PEFO ecosystems were rated as having moderate sensitivity to acidification effects (Sullivan et al. 2011a; Sullivan et al. 2011b). Overall trend was identified as "improving" and confidence in the data was "high."

4.4.2. Background and Importance

Most visitors who come to national parks expect clean air and clear views. However, air pollution on NPS lands may result in a combination of negative impacts including adverse effects on ecosystems and human health concerns (NPS 2018e), as well as diminished scenic views and visitor experience (NPS 2018e). In addition to safeguards provided by the NPS Organic Act, the Clean Air Act (CAA) provides a national goal "to preserve, protect, and enhance the air quality in national parks, national wilderness areas, national monuments, national seashores, and other areas of special national or regional natural, recreational, scenic or historic value" (USFR 1963). This goal applies to all units of the National Park System. The CAA further designates 48 National Park Service (NPS) units, including Petrified Forest National Park, as "Class I" areas, providing special protection for air quality, sensitive ecosystems and clean, clear views in these areas. The CAA aims to eliminate all human-caused visibility impairment in Class I areas by the year 2064. Additional authority to consider and protect air quality related values (AQRVs) in Class I parks is provided by the Title 54 (U.S. Code 1970), commonly known as the NPS Organic Act, and the Wilderness Act. AQRVs for Petrified Forest NP may include wilderness character, biodiversity, scenic views, night sky, vegetation, wildlife, soil, and other resources that could be degraded by air pollution.

Local and distant air pollutant sources—including power plants, oil and gas development, and the industrial and urban areas of southern California, southern Arizona, and northern Mexico—can degrade air quality at the park. There are three coal-fired power plants are within 50 miles of the park negatively contribute to park air quality conditions in the park based on the 2014 National Emission Inventory (EPA 2018a). Significant emissions reductions from these power plants are scheduled by 2018 for the protection of PEFO and other regional Class I areas under the Arizona Regional Haze State Implementation plan (EPA 2018b). Other large sources near the PEFO include a bio-fuel power plant, two natural gas compressor stations and two rail yards. In addition to human caused pollution, sand and dust from dry washes during high winds and smoke from wildfire can contribute to reduced visibility (EPA 2018a).

Air pollutants of concern include nitrogen (N) and sulfur (S) compounds (including nitrate [NO_3^-], ammonium [NH_4^+], and sulfate [SO_4^{2-}]), ground-level ozone (O_3) and fine particulates (Sullivan 2016). Potential effects to humans include visibility impairment, and ozone-induced human health problems. To better understand and protect air quality, the NPS and collaborators have monitored air quality and air quality related values at PEFO since 1988 (NPS 2018f).

Visibility

Air pollution can create a white or brown haze that affects how well and far we can see. 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 (Sullivan 2016). During the night, air-borne particulates reflect and scatter artificial light, increasing the effect of light pollution (NPS 2018g). 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 (Taylor 2017). Natural visibility conditions are those estimated to exist in a given area in the absence of human-caused visibility impairment (EPA 2003). Average natural visual range is reduced from about 170 miles (without the effects of pollution) to about 120 miles because of pollution at PEFO. The visual range is reduced to below 80 miles on high pollution days (NPS 2018h).

Ozone

Ozone is a gaseous constituent of the atmosphere produced by reactions of nitrogen oxides (NO_x) from vehicles, power plants, industry, and fire and volatile organic compounds from industry, solvents, and vegetation in the presence of sunlight (Fenn et al. 2003; Porter and Biel 2011). It is one of the most widespread air pollutants and the major constituent in smog (NPS 2018i). In addition to causing respiratory problems in people, ozone can injure plants. Ozone enters leaves through pores (stomata), where it can kill plant tissues, causing visible injury or reduced survival (NPS 2018i). Foliar damage requires the interplay of several factors, including the sensitivity of the plant to the 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 the environmental conditions, particularly adequate soil moisture, foster gas exchange and the uptake of ozone by plants (Kohut 2007).

A risk assessment that considered ozone exposure, soil moisture, and sensitive plant species concluded that plants in PEFO were at moderate risk of ozone injury to vegetation (Kohut 2007). Ozone concentrations and cumulative doses at the park are high enough to induce foliar injury to sensitive vegetation under certain conditions (Binkley et al. 1997). While the park's arid conditions often cause plant stomata to close, limiting water loss and ozone uptake, Kohut et al. (2012) reported that within mesic areas, such as along streams and seeps in the Intermountain West, plants may keep stomata open more often resulting in ozone uptake and subsequent injury. There are five known native ozone-sensitive plants in the park including **Artemisia ludoviciana* (cudweed sagewort), **Mentzelia albicaulis* (white blazingstar), **Populus fremontii* (Fremont's cottonwood), *Salix exiguia* (coyote willow), and *Salix gooddingii* (Gooding's willow); species with an * are biological indicators (NPS 2018j).

Navajo and Apache counties, Arizona (the counties in which PEFO occurs) met the 2008 NAAQS ozone standard of an 8-hour average concentration of 75 ppb (EPA 2018c); thus, satisfying the EPA-designated "attainment" for ozone. However, the EPA has not finalized the designation of areas as attainment or nonattainment for the 2015 NAAQS ozone standard (EPA 2018d).

<u>Nitrogen and Sulfur Deposition</u>
Nitrogen and sulfur compounds in air pollution (e.g., from industry, agriculture, oil and gas development) can deposit into ecosystems and cause acidification, excess fertilization, and changes in soil and water chemistry that can affect community composition and alter biodiversity (Sullivan 2016; Fowler et al. 2013).

Although nitrogen is an essential plant nutrient, surplus levels of atmospheric nitrogen deposition can stress ecosystems. Plants in arid ecosystems such as Petrified Forest's shrublands and grasslands are particularly vulnerable to changes caused by nitrogen deposition (Sullivan 2016). Ecosystem sensitivity to nutrient nitrogen enrichment at PEFO relative to other national parks has been ranked as "very high" (Sullivan et al. 2011a; Sullivan et al. 2011b). Increases in nitrogen have been found to promote invasions of fast-growing alien plant species of annual grasses (e.g., cheatgrass [*Bromus tectorum*]) and forbs (e.g., Russian thistle [*Salsola tragus*] at the expense of native species (Brooks 2003; Schwinning et al. 2005; Allen et al. 2009). Increased grasses can increase fire risk (Rao et al. 2010) with profound implications on biodiversity within non-fire adapted ecosystems. Nitrogen may also decrease water use efficiency in arid land plant groups, such as sagebrush (Inouye 2006).

Sulfur, together with nitrogen, can acidify surface waters and soils, which can result in losses in biodiversity, the release of toxic aluminum, and upset balances in nutrient cycling. PEFO ecosystems were identified as having "moderate" sensitivity to acidification effects (Sullivan et al. 2011c; Sullivan et al. 2011d). This rating was based on conditions including steep slope, high elevation headwater streams, and the abundance of surface water and vegetative types expected to be most sensitive to acidification. Surface waters along the Colorado Plateau are well-buffered from acidification, but smaller, intermittent and ephemeral streams may have little opportunity to buffer potentially acidic run-off (Binkley et al. 1997).

<u>Air Quality Standards</u>
Air quality is deteriorated by many forms of pollutants that either occur as primary pollutants, emitted directly from sources such as power plants, vehicles, wildfires, and wind-blown dust, or as secondary pollutants, which result from atmospheric chemical reactions. The CAA requires the U.S. Environmental Protection Agency (EPA) establish National Ambient Air Quality Standards (NAAQS) (USFR 2015) to regulate air pollutants considered harmful to human health and the environment. The two types of NAAQS are primary and secondary, with primary standards establishing limits to protect human health, and secondary standards establishing limits to protect public welfare from air pollution effects including decreased visibility, and damage to animals, crops, vegetation, and buildings.

The NPS' Air Resources Division (NPS-ARD) air quality monitoring program uses EPA's NAAQS, natural visibility goals and ecological thresholds as benchmarks to assess visibility, ozone, and atmospheric deposition (Taylor 2017).

4.4.3. Data and Methods

NPS-ARD uses all available data from NPS, EPA, state, and/or tribal monitoring stations to calculate air quality values. Trends are calculated from data collected over a 10-year period at on-site or nearby representative monitoring stations. For data to be included, it must be at least a six-year dataset and have data for the end year of the reporting period (i.e., a complete annual dataset for year 6). Statistical analyses are used to identify significant trends.

This assessment used methods developed by the NPS Air Resources Division (NPS-ARD) for Natural Resource Condition Assessments (NPS-ARD 2018). Conditions & Trends website (NPS 2018k) provides additional information on visibility, ozone, and nitrogen and sulfur deposition for PEFO. For this assessment, three indicators are included (visibility, ozone level, and N and S deposition) and five measures (haze index, annual 4th-highest 8-hr ozone concentration for human health, 3-month maximum 12-hr W126 for vegetation, sulfur wet deposition and nitrogen wet deposition).

4.4.4. Indicators & Measures

Indicator
Visibility
Measure
Haze Index

Visibility is monitored through the Interagency Monitoring of Protected Visual Environments (IMPROVE) Program. Visibility is expressed by the haze index in deciviews (dv), which is scored as a zero in pristine conditions and increases as visibility decreases. Haze index is a measure that corresponds to uniform incremental changes in visual perception across the entire range of conditions from pristine to highly impaired (Taylor 2017).

NPS-ARD assesses visibility condition status based on the estimated 5-year average haze index on the mid-range days minus the estimated natural visibility (i.e., those estimated for a given area in the absence of pollution). Mid-range days are where visibility is between the 40th and 60th percentiles. Annual measurements on mid-range days are averaged over a 5-year period at each visibility monitoring site with at least 3-years of complete annual data. Five-year averages are taken across all monitoring locations.

Visibility trends are computed from the annual haze index values on the 20% haziest days and the 20% clearest days, consistent with visibility goals in the CAA and Regional Haze Rule, which include improving visibility on the haziest days and allowing no deterioration on the clearest days. Although this legislation provides special protection for NPS lands designated as Class I designated viewsheds, the NPS applies these metrics to all units of the NPS. 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. Monitoring data from the IMPROVE PEFO1 site (operating since 1988) were used to determine the 10-year visibility trend at PEFO.

Petrified Forest National Park's visibility was 4.1 dv, this was based upon the estimated 5-year (2011-2015) average, which falls within the "moderate" category for visibility (NPS 2018k). For 2006-2015, the trend in visibility (Monitor ID: PEFO1, AZ) improved for both the 20% clearest days (Figure 4.4-1) and 20% haziest days (Figure 4.4-2); thus, the overall trend is considered to be "improving" (NPS 2018k). Confidence in this assessment is high because these readings were based on on-site visibility monitor. In 2015, the clearest days occurred in January and February, while the haziest days occurred during August and June (Figure 4.4-3).

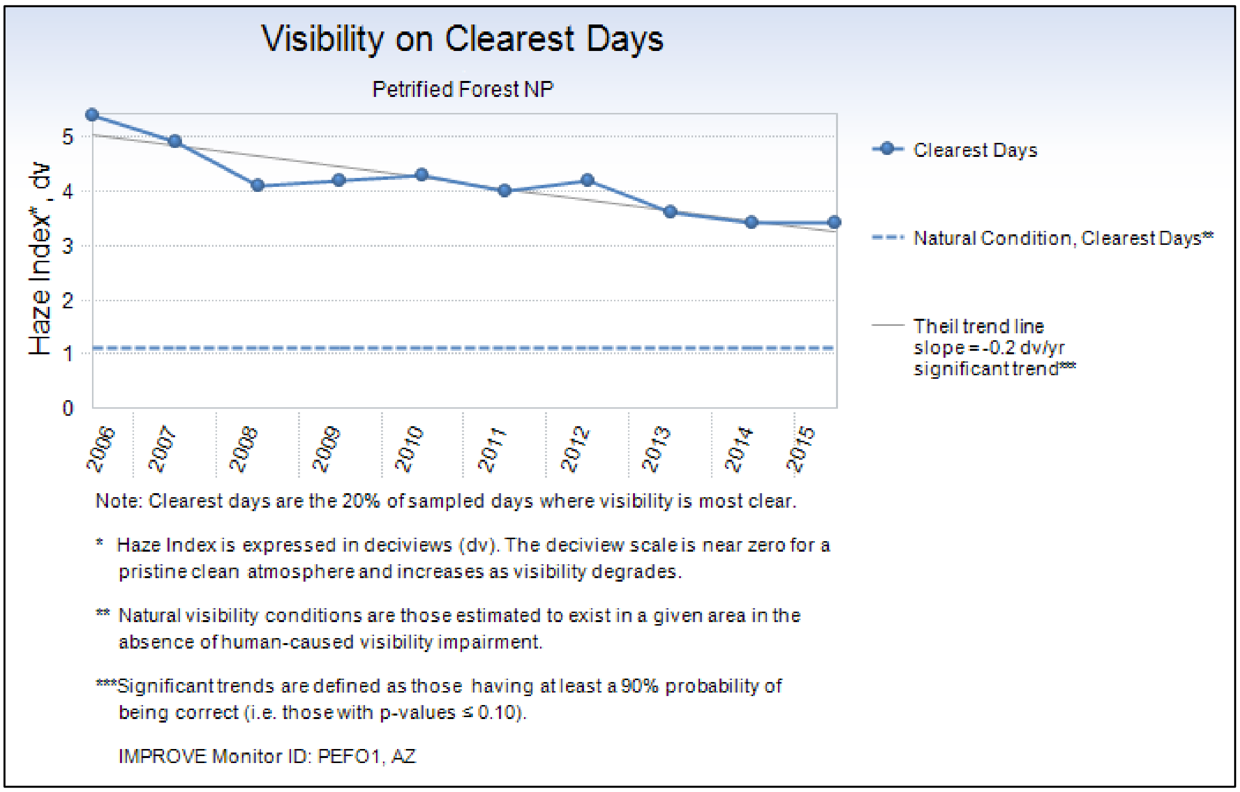


Figure 4.4-1. Visibility data for the clearest days based upon visibility monitoring instrument (PEFO1, AZ).

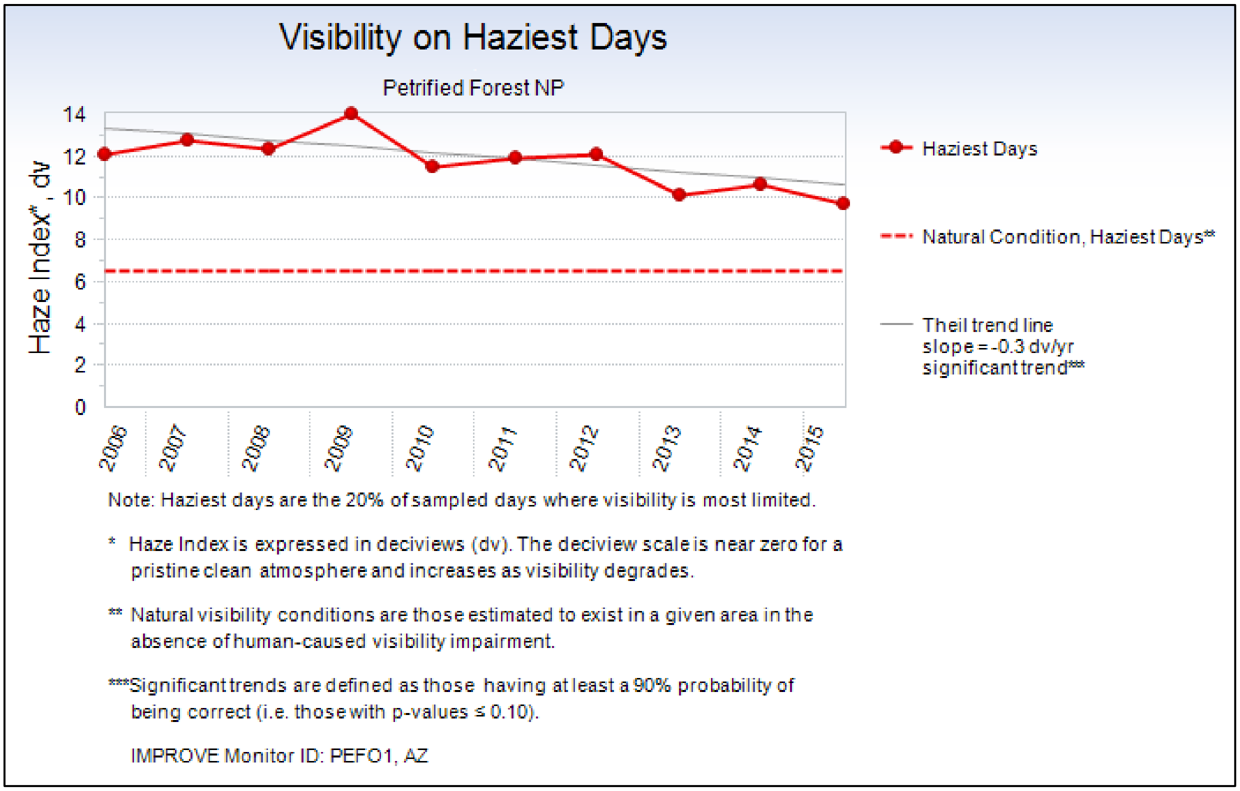


Figure 4.4-2. Visibility data for the haziest days based upon visibility monitoring instrument (IMPROVE #PEFO1, AZ).

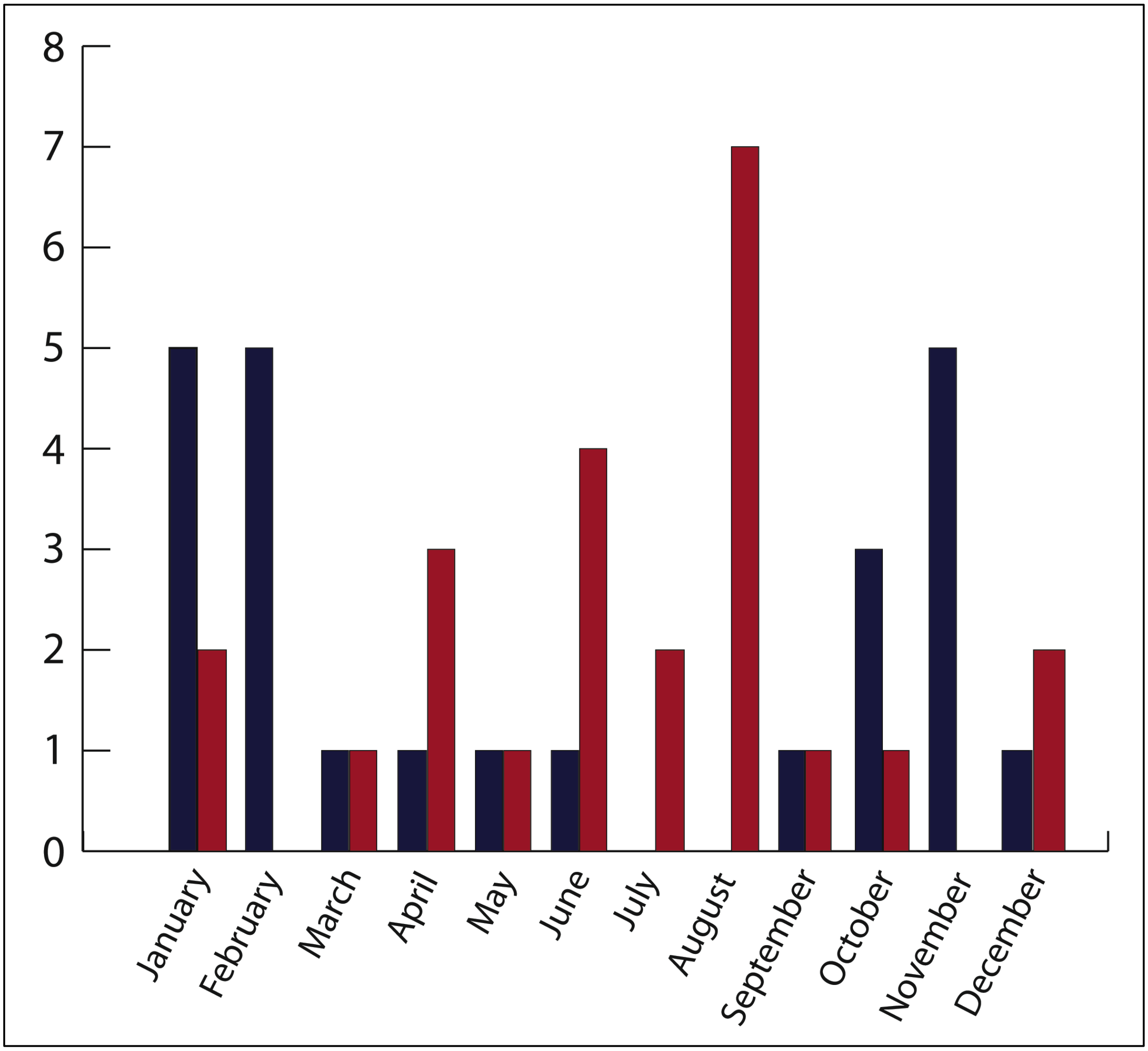


Figure 4.4-3. Distribution of haze on clearest (blue) and haziest (red) days for 2015. Clearest and haziest days are 20% of sampled days where visibility was either most clear or most hazy. Data collected from IMPROVE monitoring station #PEFO1, AZ.

Visibility impairment primarily results from airborne sand and dust particulate matter from dry washes during high wind events, and smoke emitted from seasonal wildfires, as well as anthropogenic sources from organic compounds, NO_X and SO_2 (EPA 2018a). Contributions made by different classes of particles of haze on the clearest days and on the haziest days are shown in Figures 4.4-4 and 4.4-5, respectively. For 2006 through 2015, primary contributing particulates on both clearest and haziest days were organic carbon, ammonium sulfate, and coarse mass. Organic carbon originates primarily from combustion of fossil fuels and vegetation, while ammonium sulfate originates mainly from coal-fired power plants and smelters. Sources of coarse mass include dust emanating from roads, agriculture, construction, mining operations, and other related activities.

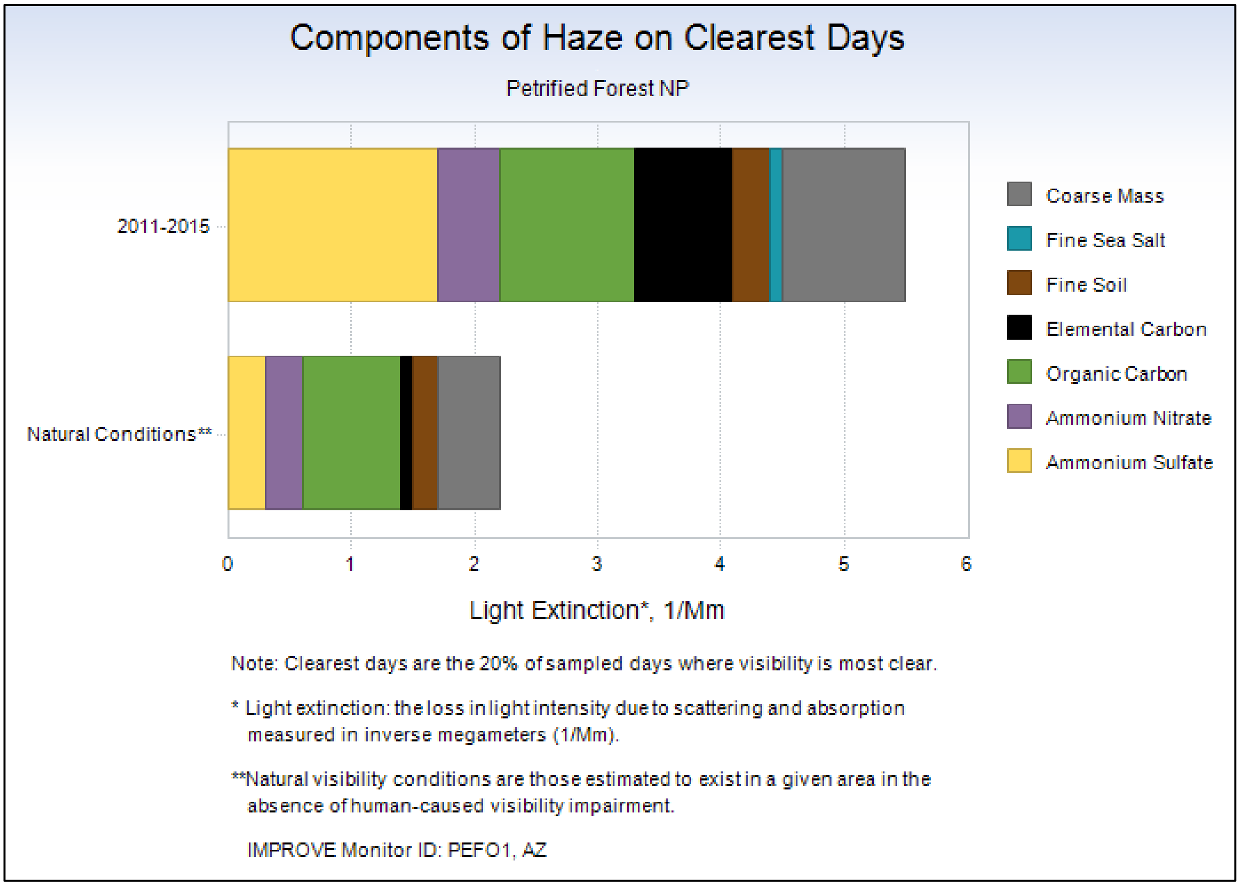


Figure 4.4-4. Components of haze on clearest days based upon visibility monitoring instrument (PEFO1, AZ).

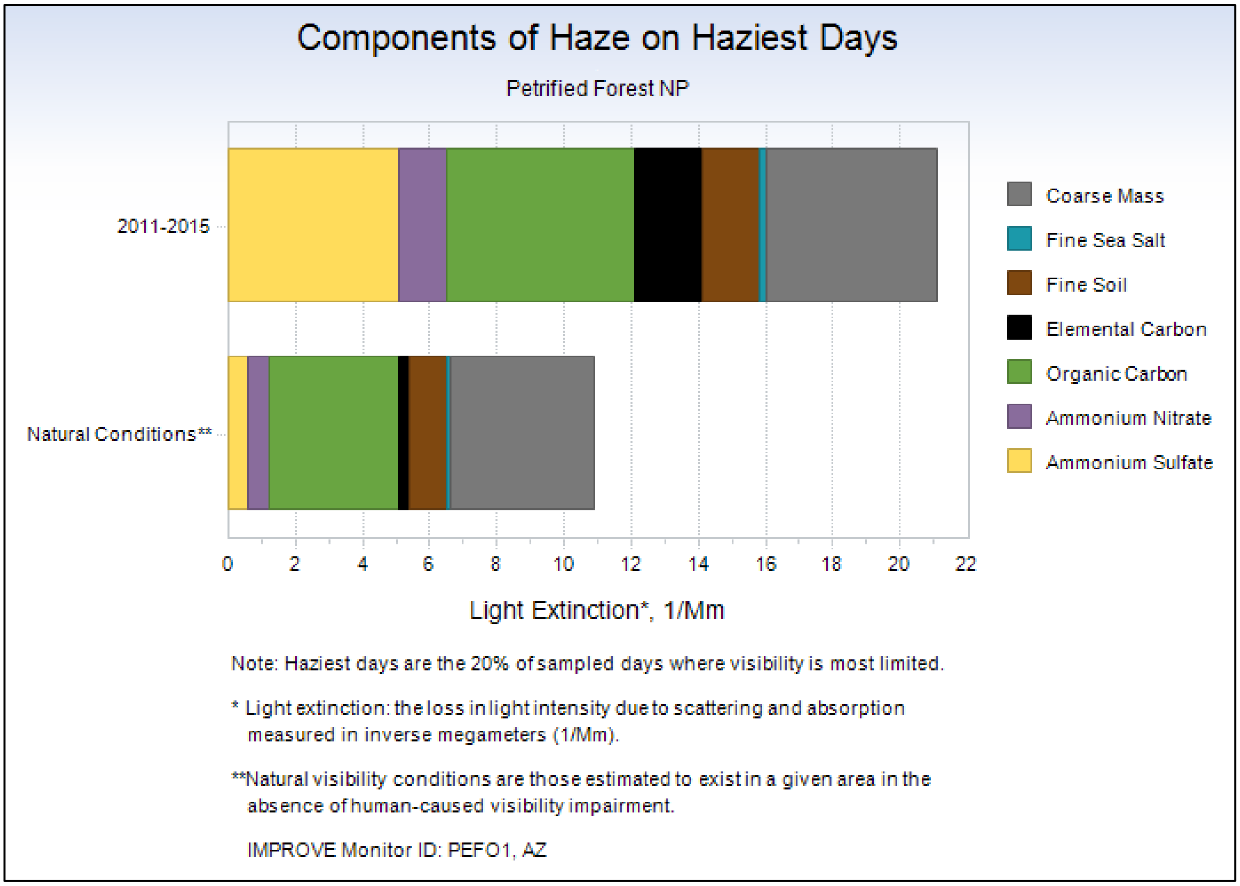


Figure 4.4-5. Components of haze on haziest days based upon visibility monitoring instrument (PEFO1, AZ).

Indicator
Ozone Level

Measure
Human Health: Annual 4th-highest 8-hr Concentration

Aggregated ozone data were acquired from the EPA Air Quality System (AQS) database. Prior to 2012, monitoring data were also obtained from the EPA Clean Air Status and Trends Network (CASTNet) database. Ground-level ozone is calculated using two statistics: 4th-highest daily maximum 8-hour average ozone concentration (human health risk measure), and 3-month maximum 12-hour W126 Index (vegetation health risk measure; Taylor 2017).

Human health risk from ozone trends are evaluated annual 4th-highest 8-hr Concentration values. Monitoring data from the 040170119 site (operating since 2003) were used to determine the 10-year visibility trend at PEFO. The primary NAAQS for ground-level ozone was set by the U.S. EPA and is based on human health effects. The 2015 NAAQS for ozone is a 4th-highest daily maximum 8-hour ozone concentration of 70 parts per billion (ppb). The NPS-ARD assesses the status for human health risk from ozone using the 4th-highest daily maximum 8-hour ozone concentration in ppb. Annual 4th-highest daily maximum 8-hour ozone concentrations were averaged over a 5-year period at all monitoring sites. Five-year averages are interpolated for all ozone monitoring locations to estimate 5-year average values for the contiguous U.S. The ozone condition for human health risk at PEFO is the maximum estimated value within the monument boundary derived from this national analysis (Taylor 2017).

The estimated five-year value (2011-2015) was 69.1 ppb (parts per billion) for the 4th highest 8-hour concentration; thus, it was considered of “moderate” concern for human health (NPS 2018g). For 2006–2015, the trend in ozone concentration at PEFO remained relatively unchanged (AQS Monitor ID: 040170119, AZ; Figure 4.4-6). Long-term trends suggest a slight improvement since 2003 (Figure 4.4-7). Confidence is high because there is an on-site or nearby ozone monitor.

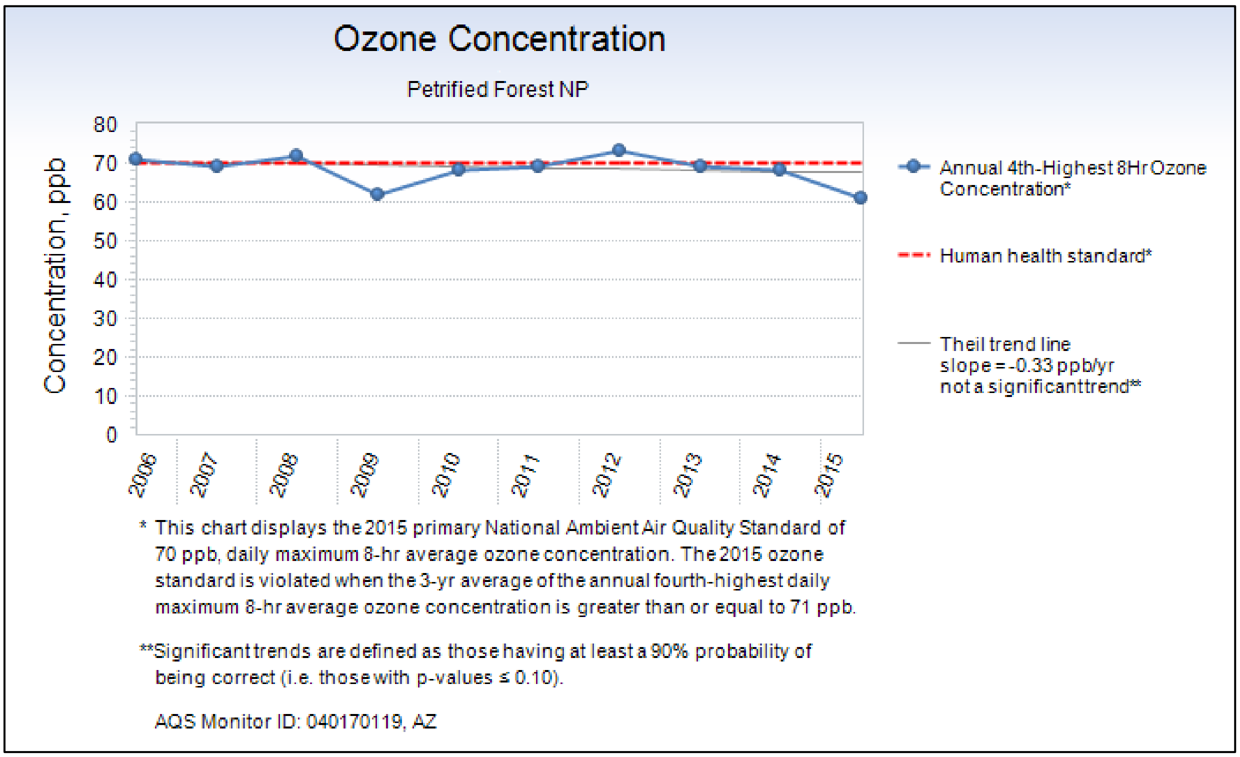


Figure 4.4-6. Ozone concentrations from 2006 through 2015 based upon the AQS Monitor ID: 040170119, AZ.

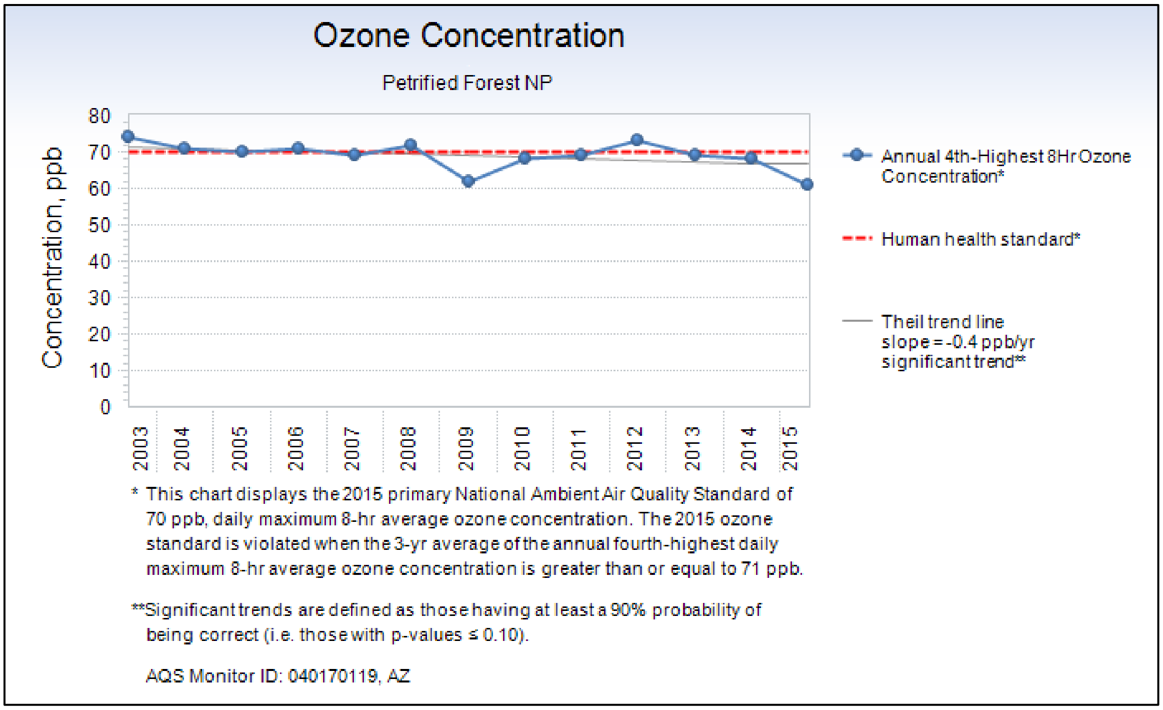


Figure 4.4-7. Ozone concentrations from 2003 through 2015 based upon the AQS Monitor ID: 040170119, AZ (NPS 2018g).

Indicator
Ozone Level

Measure
Vegetation Health: 3 month Maximum 12 hr W126

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. One annual index is the W126, which preferentially weighs the higher ozone concentrations most likely to affect plants and sums all the weighted concentrations during daylight hours (8AM–8PM). The highest 3-month period that occurs from March to September is reported in "parts per million-hours" (ppm-hrs) and is used for vegetation health risk from ozone condition assessments.

Annual 3-month maximum 12-hour W126 index values are averaged over a 5-year period at all monitoring sites with at least 3 years of complete annual data. Five-year averages are interpolated for all ozone monitoring locations to estimate 5-year average values for the contiguous U.S. The estimated current ozone condition for vegetation health risk at PEFO is the maximum value within the park boundary derived from this national analysis.

Vegetation health risk from ozone trends are evaluated annual 3-month maximum 12-hour W126 index values. Monitoring data from the 040170119 site (operating since 2003) were used to calculate these O_3 levels.

The estimated five-year (2011-2015) W126 index was 15.5 parts per million-hours (ppm-hrs); thus, the condition rating warranted a "significant concern" for human health (NPS 2018g). For 2006–2015, the trend in the W126 metric at PEFO remained relatively unchanged (AQS Monitor ID: 040170119, AZ; Figure 4.4-8). Long-term trends show improvement since 2003 (Figure 4.4-9). Confidence is high because there is an on-site or nearby ozone monitor.

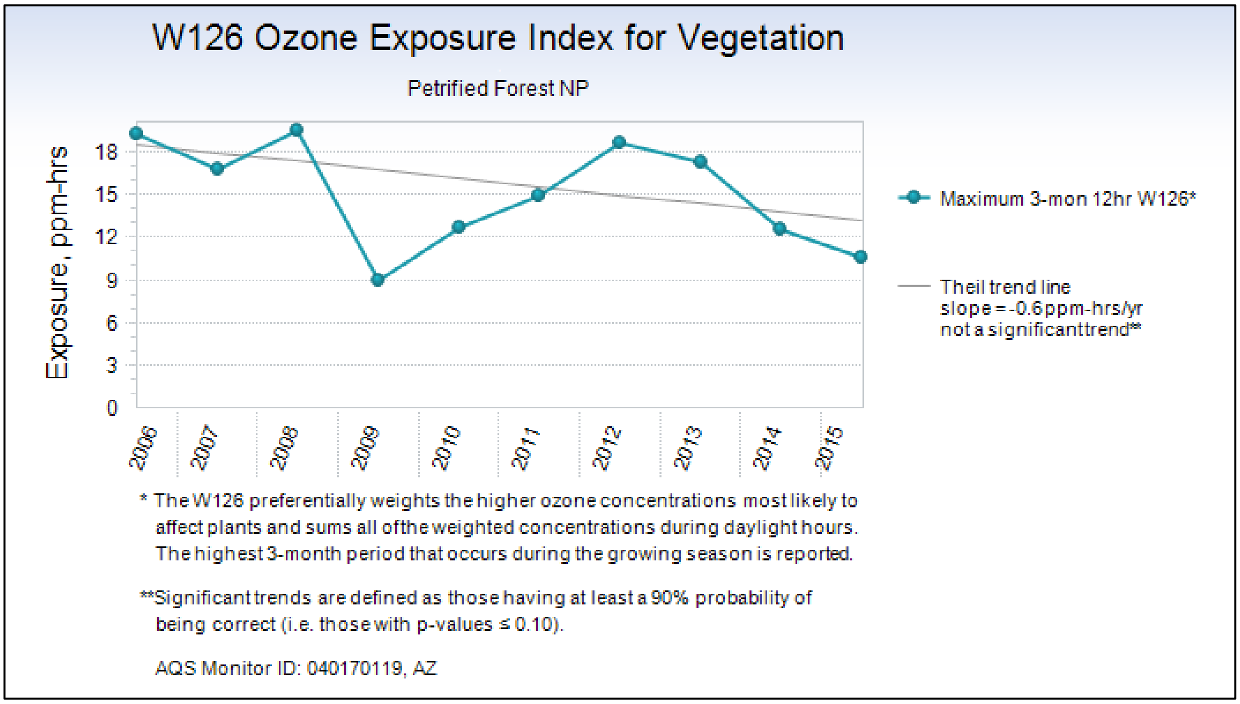


Figure 4.4-8. W126 Ozone exposure index for vegetation (2006–2015; NPS 2018g).

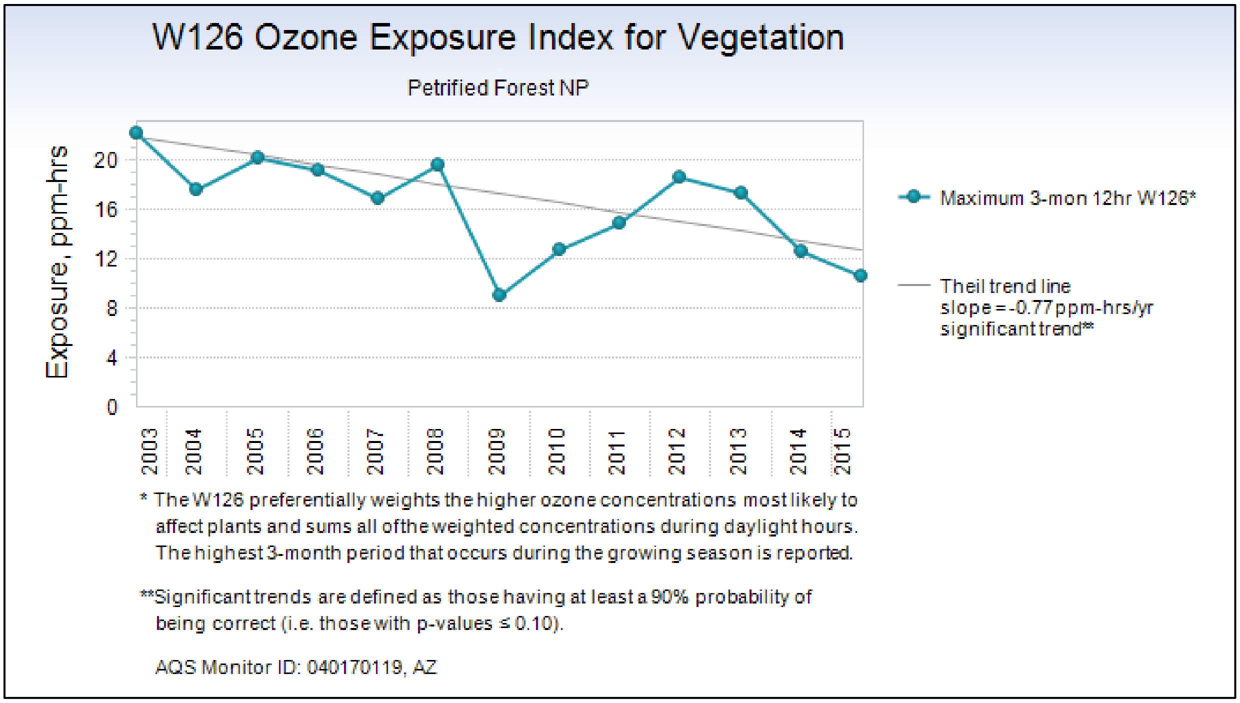


Figure 4.4-9. W126 Ozone exposure index for vegetation (2003–2015; NPS 2018g).

Indicator
Wet Deposition

Measures
Nitrogen wet deposition

Atmospheric wet deposition is monitored across the United States as part of the National Atmospheric Deposition Program/National Trends Network (NADP/NTN) for nitrogen and sulfur.

Wet deposition is used as a surrogate for total deposition (wet plus dry), because wet deposition is the only metric nationally monitored source for nitrogen and sulfur deposition data. Wet deposition values for nitrogen (N) and sulfur (S) from sulfate are expressed as amount of N or S in kilograms deposited over one-hectare area in one year (kg/ha/yr).

For N and S condition assessments, wet deposition was calculated by multiplying nitrogen (from ammonium and nitrate) or 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 three years of annual data. National five-year averages were calculated using data from all monitoring locations across the contiguous U.S. For NPS park units, maximum values are estimated from these data, which are then assigned the condition status.

Wet deposition trends are calculated using pollutant concentrations in precipitation (micro equivalents/liter). For PEFO, monitoring data from NADP/NTN AZ97 site (operational since 2003) was used to calculate the 10-year visibility trend.

The estimated five-year average value (2011-2015) was 1.3 kg/ha/yr (Table 4.4-10). This warrants "moderate" concern. However, the condition has been elevated to "significant" concern because PEFO ecosystems may be very highly sensitive to nitrogen-enrichment effects (NPS 2018g). For 2006–2015, the trend in total wet nitrogen concentration in rain and snow remained relatively unchanged (NADP Monitor ID: AZ97, AZ). Confidence is high because there is an on-site or nearby deposition monitor.

The estimated maximum 2013–2015 average for total nitrogen deposition was 3.5 kg/ha/yr in the North American Deserts ecoregion—where PEFO is located (NPS 2018l). Total nitrogen deposition levels in the park are thus above the minimum ecosystem critical loads for some park vegetation communities. In particular, lichen and some herbaceous vegetation types may be at risk (NPS 2018l; Figure 4.4-10).

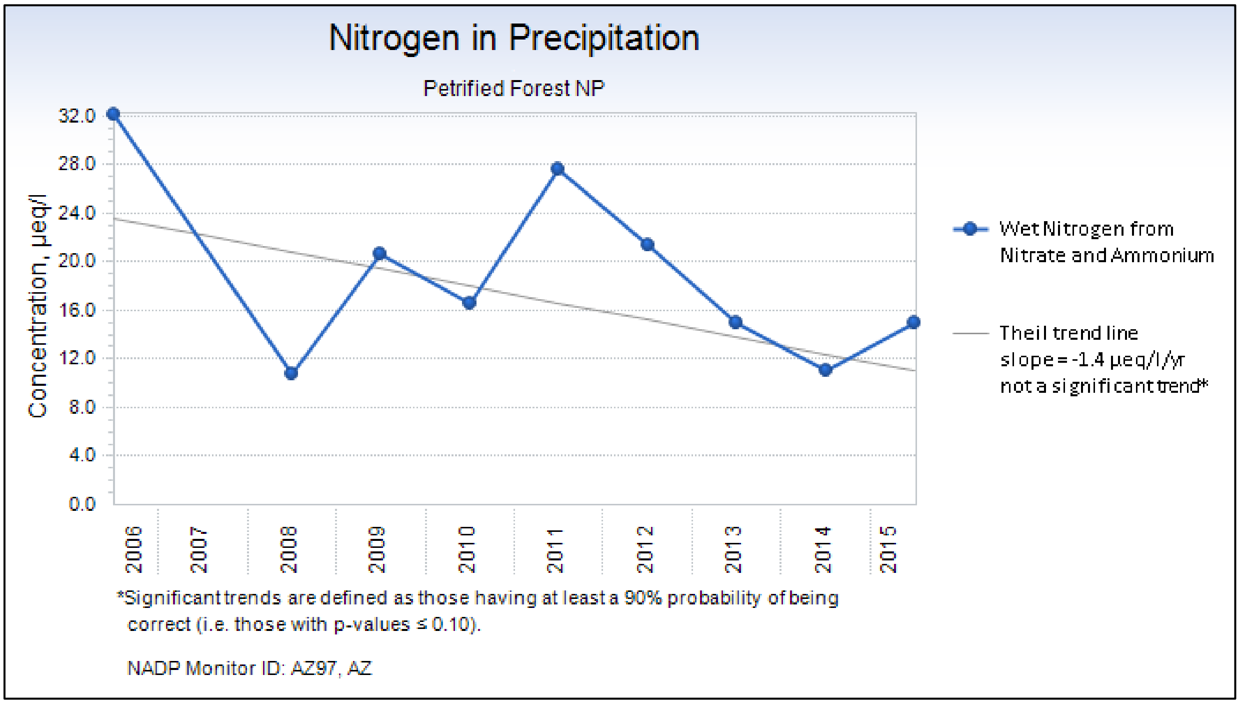


Figure 4.4-10. Nitrogen in precipitation based upon NADP Monitor ID: AZ97, AZ (NPS 2018g).

Indicator
Wet Deposition

Measure
Sulfur wet deposition

The estimated five-year (2011–2015) average value was 0.5 kg/ha/yr (Table 4.4-2); this condition is considered "good" (NPS 2018g). For the 2006–2015 period, the trend in total wet sulfur concentrations in rain and snow improved (NADP Monitor ID: AZ97, AZ). Confidence is high because there is an on-site or nearby deposition monitor.

Table 4.4-2. Average changes for Total S, Total N, Nitrogen Oxides (NO_X), and Ammonia (NH_3) between 2001 and 2011 across park grid cells, Petrified Forest National Park, Arizona. Deposition estimates were determined by the Total Deposition Project, based on three-year averages centered on 2001 and 2011 for all ~4 km grid cells (Sullivan 2016). Average per year and differences (i.e., absolute change) provided.

Pollutant	2001 Average (kg/ha/yr)	2011 Average (kg/ha/yr)	Absolute Change (kg/ha/yr)
Total S	1.5	1.26	−0.24
Total N	3.45	3.11	−0.34
NO_X	2.58	2.00	−0.58
NH_3	0.86	1.11	0.24

Sullivan (2016) reported that most counties in the vicinity of the Southern Colorado Plateau Network had relatively low levels of sulfur dioxide (SO_2) emissions (< 5 tons per square mile per year [tons/mi^2/yr]), while emissions of oxidized N were generally slightly higher (≥ 5 tons/mi^2/yr or more), and emissions of reduced N were lower (< 2 tons/mi^2/yr). Total S and N deposition at measured locations of SCPN parks from 2010 to 2012 were typically less than 2 kg S/ha/yr and 5 kg N/ha/yr, respectively (Figure 4.4-11). Hand et al. (2011) reported that overall long-term sulfate ions levels at PEFO trended downward at −3.7% yr^{-1} with winter levels at −4.7% yr^{-1}; these levels were based upon data from an IMPROVE monitoring station located at the north end of old Route 66 east.

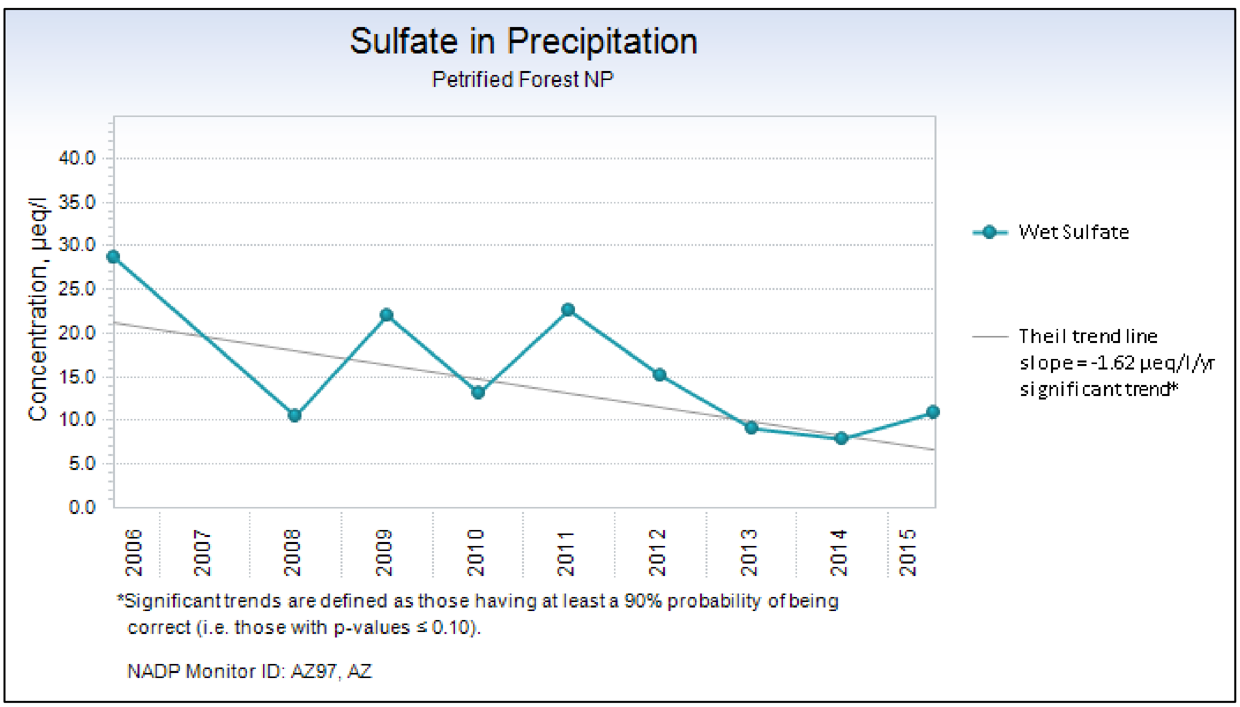


Figure 4.4-11. Sulfate in precipitation (2006–2015) based upon NADP Monitor ID: AZ97, AZ (NPS 2018g).

Sullivan (2016) reported Total S, Total N, nitrogen oxides (NO_X) and ammonia (NH_3) for 2001 and 2011. Decreases in Total S, Total N and NO_X, and a slight increase in NH_3 were reported (Table 4.4-2). Estimated acid pollutant exposure and ecosystem sensitivity to acidification is considered "low" and "moderate," respectively (Sullivan 2016). Additionally, Sullivan (2016) identified ecosystem sensitivity to nutrient N enrichment as "high," and current estimated nutrient N pollutant exposure is "low."

Importantly, regional SO_2 and NO_X emissions for the three-state area (Arizona, New Mexico and Nevada) reported a four-fold decrease between 2000 and 2014 (Sullivan 2016). SO_2 emissions dropped from ~53,000 tpy (tons per year) in 2000 to ~10,000 tpy in 2014. For the same temporal window, NO_X emissions declined from ~48,000 to ~10,000 typ.

4.4.5. Reference Conditions

Visibility (Haze Index)

A visibility condition estimate of less than 2 deciviews (dv) above estimated natural conditions is considered "good," estimates ranging between 2 and 8 dv above natural conditions is "moderate concern," and estimates greater than 8 dv above natural conditions is "significant concern." The NPS-ARD uses reference condition ranges to reflect the variation in visibility conditions across the monitoring network (Taylor 2017). Natural visibility conditions are those estimated to exist in a given area in the absence of human-caused visibility impairment. Estimated annual average natural condition on mid-range days equals 2.9 deciviews (dv) at PEFO.

Visibility trends and conditions are both expressed in terms of a Haze Index in deciviews (dv); however, the benchmark metrics are different. Condition assessments are based on estimated five-year average visibility on mid-range days (40th to 60th percentile) minus the estimated natural visibility condition on mid-range days. Visibility trends are computed from the haze index values on the 20% haziest days and the 20% clearest days.

Level of Ozone: Human Health

Human health ozone condition thresholds are based on the 2015 EPA ozone standard, which is the safe level to protect human health: 4th-highest daily maximum 8-hour ozone concentration of 70 ppb (Taylor 2017). The NPS-ARD rates ozone condition as "good" if the ozone concentration is less than or equal to 54 ppb. This is congruent with the updated Air Quality Index breakpoints (Taylor 2017), where "moderate concern" is between 55 and 70 ppb, and "significant concern" when greater than or equal to 71 ppb.

Level of Ozone: Vegetation Health

The W126 condition thresholds are based the EPA's Policy Assessment for the Review of the Ozone NAAQS (Taylor 2017). For W126 values of $\leq$ 7 ppm-hrs results in tree seedling biomass loss is $\leq$ 2 % per year in sensitive species, and $\geq$13 ppm-hrs facilitates tree seedling biomass loss is 4-10 % per year in sensitive species (EPA 2014; Taylor 2017). NPS-ARD identified a W126 of $<$ 7 ppm-hrs to protect most sensitive trees and vegetation, which is considered "good," 7-13 ppm-hrs is considered "moderate concern" and $>$13 ppm-hrs is "significant concern" (Taylor 2017).

Wet Deposition: Nitrogen and Sulfur

The 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. This is based on studies linking early stages of aquatic health decline with 1.0 kg/ha/yr wet deposition of nitrogen both in the Rocky Mountains and in the Pacific Northwest. Parks with less than 1 kg/ha/yr of atmospheric wet deposition of nitrogen or sulfur compounds are assigned "good" condition, those with 1-3 kg/ha/yr are assigned a "moderate concern" condition, and parks with depositions greater than 3 kg/ha/yr are considered to be of "significant concern" (Taylor 2017). For Nitrogen compounds, the critical level for the protection of PEFO herbaceous plants ranges from 3.0 to 8.4 kg N/ha/yr and 3 kg N/ha/yr for the protection of lichens (Ellis et al. 2013).

4.4.6. Conditions and Trend

The values used to determine conditions for all air quality indicators and measures are listed in Table 4.4-3.

Table 4.4-3. NPS-ARD reference conditions (Taylor 2017; NPS-ARD 2008, 2018) for both conditions and measures.

Air quality indicator	Significant concern	Moderate	Good
Visibility (dv)	>8	2–8	< 2
Ozone: Human Health (ppb)	≥ 71	55–70	≤ 54
Ozone: Vegetation Health (ppm-hrs)	>13	7–13	<7
N and S Wet Deposition (kg/ha/yr)	>3	1–3	< 1

Visibility warrants moderate concern. Status based on NPS (2018g) and the 2011–2015 estimated visibility on mid-range days of 4.1 deciviews (dv). For 2006–2015, visibility improved on the 20% clearest days and improved on the 20% haziest days (IMPROVE Monitor ID: PEFO1, AZ). Clean Air Act visibility goal require improvement on the 20% haziest days, with no degradation on the 20% clearest days.

Human health risk from ground-level ozone warrants moderate concern. Status based on NPS (2018g) and the 2011–2015 estimated ozone of 69.1 parts per billion (ppb). Ozone concentrations remained relatively unchanged from 2006 through 2015 (AQS Monitor ID: 040170119, AZ).

Vegetation health risk from ground-level ozone warrants significant concern. Status based on NPS (2018g) and the 2011–2015 estimated W126 metric of 15.5 parts per million-hours (ppm-hrs). Risk assessment concluded that plants were at moderate risk for ozone damage (Kohut 2007). Refer to NPS (2018f) for list of ozone-sensitive plants. For 2006–2015, W126 remained relatively unchanged (AQS Monitor ID: 040170119, AZ).

Reporting units for wet deposition conditions and trends are different. Wet deposition trends are evaluated using pollutant concentrations in precipitation (micro equivalents/liter) so that yearly variations in precipitation amounts do not influence trend analyses. Wet deposition conditions are based on nitrogen and sulfur loading (kilograms per hectare per year) to ecosystems. Wet nitrogen deposition warrants significant concern. Status based on NPS (2018h) and the 2011–2015 estimated wet nitrogen deposition of 1.3 kilograms per hectare per year (kg/ha/yr); this level normally warrants moderate concern. However, status was elevated to significant concern because PEFO ecosystems may be highly sensitive to nitrogen-enrichment effects (Sullivan et al. 2011c; Sullivan et al. 2011d). Nitrogen deposition may disrupt soil nutrient cycling and affect biodiversity of some plant communities including arid and semi-arid and grassland. Total wet nitrogen concentrations in rain and snow remained relatively unchanged during 2006 through 2015(NADP Monitor ID: AZ97, AZ).

Wet sulfur deposition is in good condition. Status based on NPS (2018g) and the 2011–2015 estimated wet sulfur deposition of 0.5 kilograms per hectare per year (kg/ha/yr). PEFO ecosystems were rated as having moderate sensitivity to acidification effects (Sullivan et al. 2011a; Sullivan et al. 2011b). Acidification effects may include changes in water and soil chemistry that impact ecosystem health. Improved. For 2006–2015, total wet sulfur concentrations in rain and snow improved (NADP Monitor ID: AZ97, AZ).

Level of Confidence

Across all measures, the level of confidence is "high." All data analyzed was collected recently from on-site visibility, ozone, and atmospheric deposition monitoring stations. Visibility and ozone data were collected from 2006 through 2015 from an onsite monitoring station (IMPROVE Monitor ID: PEFO1, AZ). For vegetation health, data was collected from 2011 through 2015 (NPS 2018g). Concerning wet deposition of nitrogen and sulfur, data was collected from 2011 to 2015 (NPS 2018l).

4.4.7. Threats, Issues, and Data Gaps

Data Gaps and Needs

Data acquisition and future planning priorities should include:

- Support for existing air quality monitoring;
- Continued nitrogen compound monitoring for early detection of elevated levels that may adversely affect PEFO ecosystems;
- Support for monitoring air quality during wildfire events and other times when haze is problematic.
- Management direction and planning efforts emphasizing efforts to protect air quality, scenic views, and resources sensitive to air pollution;
- Identification of sensitive resources, and future air quality needs, and research and monitoring (in consultation with NPS-ARD and the Regional Air Resources Coordinator);
- Monitoring of five known native ozone-sensitive plants—as determined by PEFO personnel; and,
- Predictions of future trends in air pollution, as well as the future dominant sources of pollution.

Issues

Climate change may exacerbate air pollutant concentrations and effects on resources. For example, increased summertime temperatures may lead to higher ozone levels (EPA 2009). One effect of climate change is an increase in wildfire activity (Abatzoglou and Williams 2016). Fires contribute a significant amount of trace gases and particles into the atmosphere that affect local and regional visibility and air quality (Kinney 2008). Wildfires have increased across the western U.S., and there is a high potential for the number of wildfires to grow as climate in the Southwest becomes warmer and drier (Abatzoglou and Williams 2016). Warmer conditions also increase the rate at which ozone and secondary particles form (Kinney 2008). Declines in precipitation may also lead to an increase in wind-blown dust (Kinney 2008). Weather patterns influence the dispersal of these atmospheric particulates. Because of their small particle size, airborne particulates from fires, motor vehicles, power plants, and wind-blown dust may remain in the atmosphere for days, traveling potentially hundreds of miles before settling out of the atmosphere (Kinney 2008).

4.4.8. Sources of Expertise

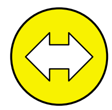
Ksienya Taylor, National Park Service, Air Resources Division, Lakewood, Colorado.

4.5. Hydrogeology

4.5.1. Condition Summary

Condition summary for hydrogeology provided in Table 4.50-1.

Table 4.5-1. Condition assessment summary of hydrogeology, Petrified Forest National Park, Arizona.

Indicator	Description	Condition Status/Trend	Summary
Alluvial water quality	Water quality is naturally poor, does not meet drinking water standards, and gets progressively worse from south to north in the park (Martin 2004). Naturally poor.		Monitoring for radionuclides is recommended given both naturally occurring uranium deposits and past mining activities upslope from PEFO (Martin 2004). As the uranium deposits occur both naturally and in tailings from previous mining activities, water quality could change in the future. Confidence is low to moderate for this condition; it is presently unchanging.

4.5.2. Background and Importance

Obtaining a reliable source of good-quality drinking water has been a problem at Petrified Forest National Park since the park's inception in 1906 (Whealan et al. 2003). There are no surface water sources in the park. There are two intermittent water sources, the Puerco River and Lithodendron Wash; both are ephemeral and unreliable source of water. Additionally, the Coconino Aquifer, which is presently accessed from a well established near the Puerco River. Water quality is poor, does not meet drinking water standards, and gets progressively worse from south to north in the park (Martin 2004). For more information on the Coconino aquifer, which extends across northeastern Arizona, refer to Hart et.al. (2002).

Considerable efforts have been expended to search for a reliable good-quality supply of potable water for park staff and visitors (Martin 2004). The only reliable sources of groundwater in or adjacent to the park are shallow, alluvial wells established along the Puerco River or deep wells (approximately 1000 feet deep) tapping into the Coconino Aquifer. Water quality of both sources is poor, and treatment would be required to meet drinking water standards. Thus, there is no source of good-quality groundwater available in or near the park (Martin 2004).

Since 1997, the park began purchasing potable water from the Navajo Tribal Utility Authority (NTUA). However, NTUA has expressed a desire to divert this supply to another area on the reservation; if this occurs, PEFO will need to secure another water supply for personnel and visitors (Martin 2004).

4.5.3. Data and Methods

This assessment was based upon the work of Martin (2004), which is both a synthesis of previous hydrogeological work on PEFO and summarizes the state of water availability for the park. Identification of all water sources within and adjacent to the park is complete. For a summary of previous investigations and reports, refer to Martin (2004). There has not been any more recent study conducted on this resource.

4.5.4. Indicators & Measures

Indicator
Alluvial water quality
Measure
Alluvial water quality

Radionuclides in the Puerco River and the alluvial groundwater are a product of both the natural erosion of uranium-bearing rock and past mining-related activities upstream of the park (Martin 2004). Groundwater in the alluvium, the source of water for the Puerco Well No. 2 has not been affected by anthropogenic releases of radionuclides upstream of the park. However, USGS concluded its water quality monitoring program of the well in 2003 (Whelan et al. 2003; Martin 2004). Intermittent sampling of the alluvial groundwater should be continued to determine whether significant water quality changes have occurred. Annual sampling and analysis may be sufficient to identify any long-term trends or water quality changes (Whelan et al. 2003; Martin 2004).

4.5.5. Reference Conditions

Identification of known water sources in and adjacent to the park is complete. No potable water source is available, and all known water sources would require purification to meet drinking water standards.

As of 2003, radionuclides in the Coconino Aquifer (from Puerco Well No. 2) have not been detected. However, water quality monitoring of this aquifer should continue, and annual monitoring should be sufficient to detect changes (Whelan et al. 2003; Martin 2004).

4.5.6. Conditions and Trend

Alluvial water quality is naturally poor, does not meet drinking water standards, and gets progressively worse from south to north in the park (Martin 2004). As the uranium deposits occur both naturally and in tailings from previous mining activities, water quality could change in the future. Confidence is low to moderate and presently unchanging.

4.5.7. Threats, Issues, and Data Gaps

Changes to water quality of Coconino Aquifer due to potential contamination of uranium radionuclides remains a concern. Monitoring would serve to detect any changes in water quality. Annual monitoring of Puerco Well No. 2 is recommended.

Data gaps and needs include a resumption of water quality monitoring at PEFO.

4.5.8. Sources of Expertise

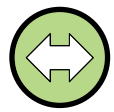
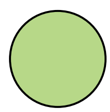
William Parker, Petrified Forest National Park, National Park Service.

4.6. Riparian

4.6.1. Condition Summary

Condition summary for riparian vegetation provided in Table 4.6-1.

Table 4.6-1. Condition assessment summary of riparian vegetation, Petrified Forest National Park, Arizona.

Indicator	Description	Condition Status/Trend	Summary
Native riparian composition and structure	Two macro-groups and nine base map vegetation classes comprising 11 native and two alien species (Thomas et al. 2009; K. Thomas, pers. com. 2018).		No data exists within park expansion lands, but richness in vegetation classes are expected to be similar; no trend possible as data was collected ~10 years ago (Thomas et al. 2009; K. Thomas, pers. com. 2018); climate change may affect species richness; however, condition presently unchanging. Using the pre-expansion lands boundary data, confidence is high.
Tamarisk occurrence & distribution	Limited primarily within the Puerco River corridor; tamarisk beetle has occurred in PEFO since 2016 (RiversEdge West 2017).		In this case, green is used to connote that Tamarisk has been effectively removed in the past, and the tamarisk beetle now occurs within the park; trend is unknown, and confidence is "medium" as tamarisk is not currently being monitored in the park.

4.6.2. Background and Importance

Numerous ephemeral washes braid the PEFO landscape. However, most of these features contain water following storm events. The Puerco River drainage area supports the only riparian plant community within the park. Based on vegetation mapping data (Thomas et al. 2009), riparian vegetation was categorized into two macrogroup map classes: (1) Inter-Mountain Basins Riparian Woodland and Shrubland (dense trees and shrubs adjacent to the river channel); and (2) Inter-Mountain Basins Wash (the shrub-dominated community that occurs along the floodplain terrace on either side of the river and within washes/ drainages). Finer scale (i.e., base map class) was used for initial mapping and classification, which are summarized in Table 4.6-2. In general, vegetation along the river corridor consists of dense stands of tamarisk (*Tamarix* spp.), and cottonwood (*Populus fremontii*) and willow trees (*Salix* spp.; Thomas et al. 2009). Floodplain terrace vegetation consists of rabbitbrush (*Chrysothamnus* spp. and *Ericameria* spp.), greasewood (*Sarcobatus vermiculatus*), and four-winged saltbush (*Atriplex confertifolia*) with scattered cottonwood (Thomas et al. 2009).

Table 4.6-2. Riparian macrogroup and base map classes, Petrified Forest National Park, Arizona (Thomas et al. 2009).

Macrogroup Map Class	Base Map Class
Inter-Mountain Basins Riparian Woodland and Shrubland	• Cottonwood / Rubber Rabbitbrush Woodland • Coyote Willow Shrubland • Tamarisk Shrubland
Inter-Mountain Basins Wash	• Barren Wash • Copperweed / Alkali Sacaton Shrubland • Drummond Goldenweed / Galleta Shrubland • Giant Sandreed Desert Wash Shrub Herbaceous Vegetation • Rubber Rabbitbrush Desert Wash Shrubland • Vegetated Wash Complex

The Southern Colorado Plateau Network (SCPN) has identified seven vital signs pertaining to riparian and spring ecosystems: 1) aquatic macroinvertebrates, 2) stream water quality, 3) stream flow and depth to groundwater, 4) spring water quality, 5) fluvial geomorphology, 6) riparian vegetation composition, and structure, and 7) spring ecosystems (Thomas et al. 2006). Of these, we considered riparian vegetation composition, and structure relevant to PEFO.

4.6.3. Indicators & Measures

Indicator
Native riparian composition and structure

Measure
Native riparian composition and structure

Riparian vegetation consists of two primary classes Inter-Mountain Basins Riparian Woodland and Shrublands and Inter-Mountain Basins Wash (Thomas et al. 2009). Within the park, the Inter-Mountain Basins Riparian Woodland and Shrublands macrogroup class was mapped to 81.8% accuracy, while the Inter-Mountain Basins Wash type was mapped to 69.4% accuracy (Thomas et al. 2009). These macrogroup classes comprised a small proportion of the park at 0.2 (66 ha) and 5.4% (2,068.4 ha) for Inter-Mountain Basins Riparian Woodland and Shrublands and Inter-Mountain Basins Wash types, respectively.

Classic riparian vegetation (i.e., Inter-Mountain Basins Riparian Woodland and Shrublands) occurs along the river corridor consists of the alien species tamarisk (*Tamarix* sp.), and a cottonwood (*Populus fremontii*) and willow (*Salix* spp.) with a shrubby understory (Thomas et al. 2009). Cottonwood trees occurred along the Puerco River corridor, and within small patches near a cattle tank in the northwestern corner within 1 km of the park boundary, and in the southwestern corner of the park along Highway 180 (Thomas et al. 2009). Few cottonwood trees remain, and most are of a large diameter with little regeneration of seedlings (Thomas et al. 2009). Inter-Mountain Basins

Wash vegetation occurs on the flood plain corridor along either side of the Puerco River, and within smaller drainages and washes feeding the Puerco River. A species list is provided in Appendix C.

Indicator
Tamarisk distribution

Measure
Tamarisk distribution

Tamarisk was first documented within the Puerco River in 1937 (Walker 1937). In 1987, PEFO was attempting to control it using a combination of manual removal and chemical treatment (Bowman 1988). According to the vegetation mapping project, tamarisk shrublands comprised 0.2% of the park (Thomas et al. 2009). The most recent efforts to control tamarisk were in 2015 (Jeff Conn, NPS, pers. com. 2019); however, a proposal for a follow-on control project was submitted in 2019 to treat tamarisk along the Puerco River Riparian (W. Parker, NPS, pers. comm. 2019). With the arrival of the tamarisk beetle arrived in 2016 (RiversEdge West 2017) and future control efforts, this extent of tamarisk in the park is expected to become smaller.

4.6.4. Data and Methods

Data for riparian zone associations were based upon Thomas et al. (2009). Barring the estimate of tamarisk shrublands extent by Thomas et al. (2009), past and current extent of tamarisk in the park is largely anecdotal. The last tamarisk treatment occurred in 2015, where two areas (each with 18 tamarisk) were treated (J. Conn, pers. com. 2019). These areas were the road crossing of the Rio Puerco south of Pinta and the old Paulsell Ranch Headquarters (W. Parker, pers. com. 2019).

4.6.5. Reference Conditions

Reference conditions would involve riparian areas free of tamarisk with native riparian vegetation in areas where tamarisk once occurred.

4.6.6. Conditions and Trend

Native riparian composition and structure: Two macro-groups and nine base map vegetation classes comprising 11 native and two alien species (Thomas et al. 2009; K. Thomas, pers. com. 2018) have been identified within the pre-expansion boundary. Although no data exists within park expansion lands, richness and vegetation classes are expected to be similar. Human induced climate change may ultimately affect species richness; however, condition presently unchanging. Using the pre-expansion lands boundary data, confidence is high. No trend is possible as data was collected ~10 years ago (Thomas et al. 2009; K. Thomas, pers. com. 2018).

Tamarisk occurrence and distribution: Tamarisk is currently limited within the Puerco River corridor. The tamarisk beetle has occurred in PEFO since 2016 (RiversEdge West 2017); however, its impact on tamarisk within the park has not been assessed. As Tamarisk has been effectively removed in the past, and the tamarisk beetle now occurs within the park, green us used to suggest the current condition for ultimately removing this nonnative invasive species. Trend is unknown, and confidence is “medium” as tamarisk is not currently being monitored in the park.

4.6.7. Threats, Issues, and Data Gaps

The greatest threats to riparian areas are: (1) cottonwood trees are not producing seeds and thus progeny for new recruitment in riparian corridors are lacking (Thomas et al. 2009), and (2) increased temperatures and drought conditions due to climate change (Butterfield and Munson 2016; Bunting et al. 2017). Additionally, the introduction of the tamarisk leaf beetles (*Diorhabda* spp.) in 2001, resulted in lower to no tamarisk and no recruitment of new cottonwood trees, species reliant upon riparian areas may be adversely impacted. Research is needed to address this potentially dramatic change in riparian habitat. Alternatively, a program to restore native riparian habitat should be explored.

4.6.8. Sources of Expertise

Kathryn Thomas, Southwest Biological Science Center, U.S. Geological Survey, Tucson, Arizona

4.7. Geology & Paleontology

4.7.1 Condition Summary

Condition summary for geology and paleontology provided in Table 4.7-1.

Table 4.7-1. Condition assessment summary for geology and paleontology, Petrified Forest National Park, Arizona.

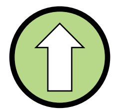
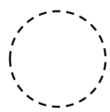
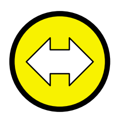
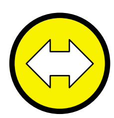
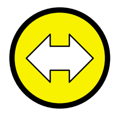
Indicator	Description	Condition Status/Trend	Summary
Damage to paleontological resources	Fossils are constantly being exposed/discovered through erosional processes; a park program removes fossils as before they are lost to erosion; The information collected over the past 110 years needs to be synthesized into a comprehensive database that may be queried by park officials.		As less than 50% of the park has been surveyed for paleontological resources, the extent of fossil deposits and the future discoveries to be made is quite high; however, park officials assert the condition is “good” and trend in reducing the damage to paleontological resources is improving. The information represents a 110 year dataset, confidence that the data is up-to-date is “high.”
Petrified wood theft	No effective measures have been developed to prevent illegal removal of petrified wood in its entirety, nor does a viable method to prevent it in the future exist.		Because there’s no means to quantify impacts of illegal theft of petrified wood, condition, trend and confidence are unknown.
Erosion/ infrastructure damage (in bentonite areas)	Managers are aware this is a problem for infrastructure and have an ongoing cyclic maintenance program to monitor and mitigate any erosional impacts. Repairs and stabilization to both Painted Desert Inn and the Painted Desert Visitor Complex are ongoing.		A geologic base map exists for the pre-2004 park boundary; thus, the extent of bentonite areas are documented; however, impacts have not been quantified. Concern for future impacts due to erosion is “moderate”; as the extent of areas susceptible are known, the trend is largely “unchanging” and confidence in the data is ‘high.
Mass wasting	All buildings and roads, especially those at Painted Desert Inn and the Blue Mesa loop should continue to be monitored.		A geologic base map exists; so regions where mass wasting occurs has been documented. Concern for future impacts due to erosion is “moderate”; as the extent of areas susceptible are known, the trend is largely “unchanging” and confidence in the data is “high.”

Table 4.7-1 (continued). Condition assessment summary for geology and paleontology, Petrified Forest National Park, Arizona.

Indicator	Description	Condition Status/Trend	Summary
Potash extraction (adjacent to and beneath the park)	Managers and geologists know the extent of the potash deposit; currently, no mining is underway. While there are currently no impacts associated with the potash deposit, if market forces shift, mining could commence, and the trend may change.		Although the potash deposit in the Holbrook Basin (which extends beneath park lands) is not presently being mined, this could change if there is an upturn in potash demand and mining the deposit becomes economically viable. Where the NPS has management of surface lands (NPS management / public ownership), the NPS will need to explore opportunities to acquire mineral rights. Concern for future impacts related to mining is "moderate"; as the extent of the area to be impacted is known, the trend is largely "unchanging" and confidence in the data is "high."

4.7.2. Background and Importance

Geology – Geologic resources comprise the scenery and the landscape that is integral to the significance of most natural areas. Geology serves as the foundation of ecosystems, and is a major determinant of topography, water and soil chemistry, fertility of soils, stability of hill slopes, and flow regimes of surface water and groundwater. These factors, in turn, influence biology, including the distribution of habitats and the locations of threatened and endangered species. Geology also influences human settlement patterns and how people use natural resources—for farming, ranching, mining, industry, construction, hunting, fishing, and recreation.

This resource also comprises "geoheritage." The National Park Service defines geoheritage as "the significant geologic features, landforms, and landscapes characteristic of our nation which are preserved for the full range of values that society places on them, including scientific, aesthetic, cultural, ecosystem, educational, recreational, tourism, and other values" (NPS 2013).

At Petrified Forest National Park, the geologic resources are integral to both landscape views, its impact in sculpting both ecosystems and human use over millennia, as well as serving as the matrix for extensive paleontological resources. The primary geologic unit exposed at the park is the Chinle Formation, an Upper Triassic sedimentary sequence of sandstone, siltstone, and claystone deposited in rivers, lakes, floodplains, and soil horizons in a sub-tropical, seasonally-wet environment. The sediments are rich in altered volcanic ash and expanding bentonite, which contributes to the erosion rate of as much as 1 cm/year (Colbert and Johnson 1981).

Paleontology –Petrified Forest National Park was set aside to preserve "the mineralized remains of Mesozoic forests" in one of the Earth's largest accumulations of silicified wood and recent additions have added privately owned lands within the expanded boundary (NPS 2008). Fossil vertebrates have been collected from the park ever since John Muir found reptile bones near Crystal Forest in the early 1900s (Parker 2006). Most of the vertebrate fossils belong to the group Archosauria, a group that includes modern birds, crocodylians and their closest extinct relatives, such as non-avian dinosaurs.

The ongoing paleontological inventory at PEFO has revealed that erosion is the primary cause of damage to vertebrate fossil resources. The NPS has compiled various guidance documents, primarily the Natural Resource Management Reference Manual 77 (NPS 2004) and Museum Handbook (NPS 2003), to assist managers and curators in avoiding damage and to manage paleontological resources. In addition, the Geological Society of America developed a paleontological monitoring manual whereby they identified five vital signs for paleontological resources (Santucci et al. 2009); two of these, erosion and human impacts were identified as measures/indicators and discussed below. Collection and curation before fossils are lost to erosion remains the key to fossil preservation (NPS 2004).

4.7.3. Data and Methods

The majority of this assessment was based upon the geologic resources report (KellerLynn 2010). Many of the research papers and reports cited in this assessment were reviewed and presented in that report. Additionally, PEFO Chief of Science and Resource Management, Dr. William Parker, and Paleontologist, Dr. Adam Marsh provided direct guidance in developing this chapter.

A species list of known fossil species to PEFO is also provided in Appendix D.

4.7.4. Indicators & Measures

Indicator Damage to Paleontological Resources
Measure Damage to Paleontological Resources

While largely preserved for more than 200 million years, persistent erosional processes are the most significant factor in the exposure of PEFO vertebrate fossils. If not promptly removed once exposed, natural weathering (such as mass wasting, see below) can damage vertebrate fossils prior to surface exposure. As these materials naturally erode to the surface, they become severely damaged and ultimately destroyed. Several physical characteristics of the rock matrix (e.g., rock type, hardness, and cementation), bedding, and degree of slope contribute to the rate of erosion (KellerLynn 2010).

Second only to erosion, inappropriate collection and removal methods can further hasten the loss and deterioration of paleontological resources (Parker and Clements 2004). Some of this damage has occurred during permitted research projects (Parker and Clements 2004). Examples of inappropriate collection methods include partially excavated, abandoned specimens later destroyed by the natural forces of erosion; improperly prepared or heavily damaged specimens; specimens collected without clear research plans and/or proper documentation; and undocumented specimens collected by untrained workers of scientists with permits (NPS 2004, 2010).

Several guidance documents and programs are available to more effectively manage and monitor the paleontological resources of PEFO. Guidance includes both the NPS Paleontological Resources Management, Natural resource management reference manual 77 (NPS 2004), the NPS Museum Handbook (NPS 2010), and a chapter on monitoring paleontological materials in a reference manual developed by the Geological Society of America (Santucci et al. 2009). Furthermore, PEFO has implemented a park paleontology program in 2001, which includes surveys and monitoring, as well as collection and curation of materials for future preservation and study. Subsequently, our scientific understanding of the fossils in the park between 208–228 million years old has increased fivefold (W. Parker, pers. com. 2018).

As less than 50% of the park has been surveyed for paleontological resources, the extent of fossil deposits and the future discoveries to be made are unknown; however, park officials assert the condition is "good" and trend in reducing the damage to paleontological resources is improving. The information represents a 110 year dataset, confidence that the data is up-to-date is "high."

Indicator
Petrified Wood Theft by Visitors

Measure
Petrified Wood Theft by Visitors

Each year, it is believed that several tons of petrified wood (PW) might be removed from the park by visitors (KellerLynn 2010). Historical estimates regarding PW loss are variable and may not reflect reality. Roggenbuck et al. (1997) conducted a study to examine visitor behavior at Long Logs and Crystal Forest, two popular petrified wood sites. During this study, 125 people were observed stealing petrified wood within 122 hours; an average of ~1.02 thefts per hour (Roggenbuck et al. 1997).

Because of this persistent problem, the park has implemented several programs over the years to minimize PW thefts (Monkevich et al. 1994; Roggenbuck et al. 1997). Widner and Roggenbuck (2000) and Attarian (2003) suggested that both educational outreach and park official presence reduce the incidence of purloined PW. A variety of print, web-based, and on-the-ground interpretation techniques can also maximize the number of visitors informed regarding park regulations and the stewardship mission of the NPS (Roggenbuck et al. 1997). For example, 76% of the park visitors surveyed indicated the park brochure was the most useful for learning about the park's rules and regulations. Widner and Roggenbuck (2000) studied deterrents to reduce theft; the study found that signs, park official presence and signing a pledge not to take PW were all effective in reducing the incidents of PW removal.

Collection within the Expanded Boundary: Most of the once in-situ petrified logs have been removed from the formerly private land acquired as part of the 2004 boundary expansion, although most of the logs within the State of Arizona trust lands remains in place (NPS 2008). Although collection of PW is prohibited on federal and unleased state lands in Arizona, removal was legal on the private lands within the expanded boundary of Petrified Forest National Park (KellerLynn 2010). Extraction of

PW and associated impacts could occur on nearly 32,000 hectares (80,000 acres) of privately-owned lands within the expanded boundary (NPS 2008).

Research suggests that banning PW sales at PEFO would lead to an increase in theft (NPS 2006b). Roggenbuck et al. (1997) found that 65.5% of visitors surveyed strongly agreed that being able to buy PW in the concessioner-operated gift shops within the park reduced the temptation to illegally remove PW from the park. As a result, PW souvenirs are sold at gift shops in the park. As the sale of original paleontological specimens is prohibited in parks (NPS 2006b), PW sold in gift shops have been obtained from areas outside the park.

Indicator
Erosion/ Infrastructure Damage in Bentonite Areas

Measure
Erosion/ Infrastructure Damage in Bentonite Areas

The siliciclastic beds of the Chinle Formation have shaped the badlands within the park for almost ten million years (Whitelaw 1992; Dallegge et al. 2003). These badlands contain bentonite, an aluminium phyllosilicate clay, which can absorb large quantities of water and thus expands considerably during heavy rains (KellerLynn 2010). As bentonite badlands expand and contract with fluctuations in moisture, the upper few centimeters of the ground heaves and buckles. The result is rapid erosion, sinkholes, and piping. In bentonitic areas where development and infrastructure occurs (i.e., administrative buildings, historic structures and roadways), these processes can damage both structures and infrastructure.

Indicator
Mass Wasting

Measure
Mass Wasting

Mass wasting is a natural geological process involving the downslope movement of bentonitic mudstone along slippage planes. Areas in the Chinle Formation at the park, such as slump blocks along the cliffs of Pintado Point and cliff retreat near Newspaper Rock and along Blue Mesa, could be of interpretive interest to park visitors (KellerLynn 2010). However, any park infrastructure (e.g., Blue Mesa loop road) located downslope from mass wasting events are most vulnerable to this natural geological process. If mass wasting threatens roadways, trail networks or other infrastructure, mitigation will be required. To address this proactively, park manager should develop strategies for early recognition, avoidance, or corrective engineering.

Indicator
Potash Extraction Within and Adjacent to Park

Measure
Potash Extraction Within and Adjacent to Park

Potash, which is comprised of potassium compounds and potassium-bearing materials, with potassium chloride being most common. Its primary economic utility is in the production of commercial fertilizer. While potash prices have steadily increased by ~20 percent annually, the World Bank indicates fertilizer prices are forecasted to decline by 4 percent in 2017 and will fall further in 2018 (Shaw 2017). China has lowered export taxes on nitrogen, phosphorus and potash (Shaw 2017), which will further lower the economic viability of developing a regional potash mine in the short term. However, as supply and demand shift over time, potash deposits like those within the park may ultimately become economically viable.

The most prominent regional potash deposit is within the Holbrook Basin, a structural basin that extends into a significant portion of Petrified Forest National Park where the subsurface mineral rights are not owned by the park (NPS 2008; KellerLynn 2010). The stratigraphic location of the deposit (which is several hundred feet below the Chinle Formation) may allow for underground mining techniques to exploit the potash without the need for open pit surface mining within the expanded boundaries. NPS (2010) suggests a single surface location could access the deposit, centralizing impacts; however, because of the size of the deposit, the surface footprint could cover hundreds of acres and may require multiple work areas.

4.7.5. Reference Conditions

Because geological and paleontological resources are largely in-situ and thus cannot be fully assessed, it is difficult to establish reference conditions. However, a species list of known plants and animals identified from the fossil record within the park is provided in Appendix D.

4.7.6. Conditions and Trend

Damage to paleontological resources: As less than 50% of the park has been surveyed for paleontological resources, the extent of fossil deposits and the future discoveries to be made is quite high; however, park officials assert the condition is "good" and trend in reducing the damage to paleontological resources is improving. The information represents a 110 year dataset, confidence that the data is up-to-date is "high."

Petrified wood theft: No effective measures have been developed to prevent illegal removal of petrified wood in its entirety, nor does a viable method to wholly prevent it in the future exist. Thus, the condition, trend and confidence are unknown.

Erosion/ infrastructure damage (in bentonite areas): A geologic base map exists for the pre-2004 park boundary; accordingly, the extent of bentonite areas are documented. However, impacts in these areas have not been quantified. Concern for future impacts due to erosion is "moderate"; as the extent of areas susceptible are known, the trend is largely "unchanging" and confidence in the data is "high."

Mass wasting: A geologic base map exists, so regions where mass wasting occurs has been documented. Concern for future impacts due to erosion is "moderate"; as the extent of areas susceptible are known, the trend is largely "unchanging" and confidence in the data is "high."

Potash extraction (adjacent to and beneath the park): The potash deposit in the Holbrook Basin (which extends beneath park lands) is not presently mined. However, this could change if there were an incease in demand and mining the deposit becomes economically viable. Where the NPS has management of surface lands (NPS management / public ownership), the NPS will need to explore opportunities to acquire mineral rights. Concern for future impacts related to mining is "moderate;" as the extent of the area to be impacted is known, the trend is largely "unchanging" and confidence in the data is "high."

4.7.7. Threats, Issues, and Data Gaps

Damage to paleontological resources: It is not feasible to establish a reference condition for damage to paleontological resources—owing either to erosion or improper scientific procedures and inadequate collection efforts. Given that it is impossible to identify and assess all paleontological resources in situ or arrest the natural process of erosion, deterioration of paleontological resources will continue. However, future damage to fossil resources associated with park permitted scientific research may be mitigated through rigorous screening of researchers during the research permit application process, requiring best practices for scientific collection are stringently followed and park monitoring of paleontological research activities. The use of approved collection techniques and museum practices allows for the collection of eroding fossils and ensures their long-term stability in museum collections.

As most of the park (~50%) has been surveyed for paleontological resources (W. Parker, pers com. 2018), new paleontological discoveries will further develop the paleontological context of the park with respect to the rest of the Colorado Plateau and the Upper Triassic around the world. As erosion is a continuous process, all previously surveyed areas must be monitored following a heavy rain event. Fortunately, park managers and researchers know which geological layers are the most productive paleontologically; thus, much of the monitoring effort goes towards those areas. To strategize how best to proceed with future paleontological fieldwork, an assessment of the entire park should be conducted. While the frequency of illegal removal of petrified wood has been estimated, there are no documented cases of theft of other paleontological resources (i.e., vertebrate fossils); subsequently, we did not include this as an indicator or measure. However, these geospatial tools will also enable park managers to identify areas that should be monitored to reduce the potential theft of vertebrate fossils. Finally, information collected over the past 110 years needs to be synthesized into a comprehensive database that may be queried by park officials.

Theft of petrified wood: One of the greatest needs for PEFO is a study using systematic techniques to assess PW theft. Over the years, attitudes about the protection of petrified wood have evolved. Today, the park has a "zero tolerance" policy regarding the illegal collection of petrified wood within the park boundary (KellerLynn 2010). Additionally, as more effective measures are developed and tested, these should be implemented. Furthermore, the park should continue to promote a sense of stewardship within each visitor so that they can share a sense of ownership in the park and thus hopefully aid in ensuring the preservation of PW and other sensitive park resources.

Erosion/ damage within and mass wasting downslope from in bentonite areas: Continued cyclic monitoring of roads and infrastructure has been, and will continue to be, an effective measure for reducing damage due to erosion/ mass wasting in bentonite areas.

Potash extraction adjacent to park: The geospatial extent of the potash deposit has been well defined. As the park does not own the mineral rights, market forces may ultimately dictate exaction of this deposit. As it will be difficult to predict if or when this will transpire, the park should conduct an assessment of the potential impacts that mining operations adjacent and/or beneath the park, as well as develop mitigation strategies to reduce the impacts to both park resources and infrastructure.

4.7.8. Sources of Expertise

- Dr. William Parker, Chief of Science and Resource Management, Petrified Forest National Park, Petrified Forest, Arizona.
- Dr. Adam Marsh, Paleontologist, Petrified Forest National Park, Petrified Forest, Arizona.

4.8. Cryptobiotic Soil Crusts

4.8.1. Condition Summary

Condition summary for cryptobiotic soil crusts provided in Table 4.8-1.

Table 4.8-1. Condition assessment summary for cryptobiotic soil crusts, Petrified Forest National Park, Arizona.

Indicator	Description	Condition Status/Trend	Summary
Damage to soil crusts	Cryptobiotic soils assist with nutrient cycling, water filtration, reduce soil evaporation rates and soil stability; the latter serves to reduce dust emissions; erosion may be the greatest impact to soil biocrusts—additional small scale impacts include damage by human visitors venturing off established trails and pedestrian ways where they inadvertently cause damage, and occasional rogue cattle that entering the park boundary.		Soil biocrust development is likely on sandier soils on PEFO. No estimates are available for percentage of soil crust land cover, nor has there been surveys to establish a baseline; thus, condition, trend and confidence is "unknown."

4.8.2. Background and Importance

Cryptobiotic soil crusts occur across numerous vegetation associations and are interspersed with vascular plant cover. Soil crusts are comprised of cyanobacteria, lichens, mosses, green algae, microfungi, and other bacteria (Belnap 1990). No estimates are available for percentage of soil crust land cover on PEFO. However, Belnap (1990) suggests for the higher elevation deserts on the Colorado Plateau region (e.g., Utah, Colorado, New Mexico and Arizona including PEFO), soil crusts may comprise between 70 to 80 percent of the "living ground cover." Ecologically, cryptobiotic soils assist with nutrient cycling (Harper and Pendelton 1993; Belnap 1994), water filtration, reduce soil evaporation rates (Brotherson and Rushforth 1983) and soil stability (Belnap 1994). The latter function serves to reduce dust emissions (Rosentreter and Eldridge 2002). Implementing practices to protect soil biocrusts both within and adjacent to the park will aid in reducing dust emissions (Belnap et al. 2009)—thus maintaining PEFO's high quality viewsheds.

4.8.3. Indicators & Measures

Indicator
Damage to Soil Biocrusts

Measure
Damage to Soil Biocrusts

Not enough information to conduct assessment.

4.8.4. Data and Methods

Soil biocrust development is likely on sandier soils on PEFO, as biocrusts typically don't develop on clay soils derived from the Chinle Formation (M. Bowker, pers. com. 2017). We were unable to find any reports or peer-reviewed publications indicative of previous work on PEFO soil biocrusts.

4.8.5. Reference Conditions

Not enough information. No reference conditions identified.

4.8.6. Conditions and Trend

Soil biocrust development is likely on sandier soils on PEFO. No estimates are available for percentage of soil crust land cover, nor has there been surveys to establish a baseline; thus, condition, trend and confidence is "unknown."

4.8.7. Threats, Issues, and Data Gaps

Erosion may be the greatest impact to soil biocrusts (refer to Paleontology and Geology chapter). Additionally, small-scale impacts include damage by human visitors venturing off established trails, pedestrian ways, and overlooks where they inadvertently cause damage. Another threat are rogue cattle that occasionally enter the park boundary.

Data gaps include a lack of data on the occurrence and extent of soil biocrusts. Based upon available information, a predictive geospatial map may be developed using covariates describing where biocrusts occur and/or form in other areas. This predictive map may then guide field survey efforts. The final product will be a largely verified geospatial distribution of soil biocrusts in PEFO. When biocrusts are present within or at proximity to human use areas, a combination of fenced enclosure construction and signage posting in key locations will serve to protect these areas.

4.8.8. Sources of Expertise

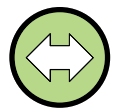
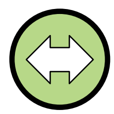
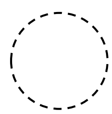
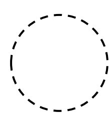
- Matthew Bowker, School of Forestry, Northern Arizona University
- Andy Bridges, Petrified Forest National Park

4.9. Grasslands

4.9.1. Condition Summary

Condition assessment for grasslands provided in Table 4.9-1.

Table 4.9-1. Condition assessment summary of grasslands, Petrified Forest National Park, Arizona.

Indicator*	Description	Condition Status/Trend	Summary
Grassland community extent	13 grassland communities encompassing ~16,640 ha (Thomas et al. 2009a)		Geospatial analysis conducted by Thomas et al. (2009a). As the extent of grasslands are known and these systems are not currently being impacted by human activities, the condition is “good.” Changes in extent and species composition likely to occur due to climate change; however, presently, trend is “unchanging.” As the extent of grasslands is well documented, confidence is “high.”
Native grassland species richness and composition	63 native grassland species (Hansen and Thomas 2006).		No data within park expansion lands, but richness is expected to be similar. Same impacts and considerations apply as for “grassland community extent”; condition “good,” trend “unchanging” and confidence “high.”
Alien plant species occurrence	21 alien plant species (Hansen and Thomas 2006); distributions appear limited to road corridors and developed areas (Thomas et al. 2009b).		Study required to map distributions and manage existing species and detect/ eradicate newly colonizing species. Last survey was conducted 13 to 23 years ago and no monitoring program alien plant species exists. Thus, condition, trend, and confidence is “unknown.”
Ratio of native to alien plant species	Ratio of native to alien plant species is 63:21 (Hansen and Thomas 2006).		This ratio was based upon a 13 years old dataset. This ratio may have changed with newly colonizing alien species. As no alien plant species monitoring program exists, condition, trend, and confidence is “unknown.”
Vertebrate indicator species	Gunnison’s prairie dog and grassland birds are assessed in individual chapters.	Refer to respective chapters for assessments.	Refer to Gunnison’s prairie dog and grassland birds’ assessment.

* Assessment based upon projects conducted within pre-2004 park boundary. No data is available for the park expansion lands.

4.9.2. Background and Importance

The park’s most widespread and environmentally important vegetation community is grasslands. Representing at least 13 different grassland associations (Table 4.9-2; Thomas et al. 2009a) and 84 grass species (Appendix E; Hansen and Thomas 2006), PEFO grasslands comprise nearly 70% of the land cover within the pre-2004 park boundary (Thomas et al. 2009a). Of these, only one species is listed by either federal or state agencies. The gladiator milkvetch (*Astragalus xiphoides*) is considered a State of Arizona Special Status Species (ADFG, 2016b). Additionally, much of PEFO's grassland topography is overlain on sand sheets, sand ramps along the mesa edges, and various exposed dunes. Within the park expansion areas, grassland species composition and structure are not known, as they have not been characterized on the ground. However, an approximate 1 km buffered area around the park was mapped using aerial photography, which captured some of the expansion lands.

Table 4.9-2. Thirteen grassland types, their associated alliances and the area (in ha), Petrified Forest National Park, Arizona (Thomas et al. 2009b).

Grassland Type	Alliance	Area (ha)
Atriplex obovata / Sporobolus airoides – Pleuraphis jamesii Shrub Herbaceous Vegetation	*Sporobolus airoides – Pleuraphis jamesii* Shrub Herbaceous Alliance	11,046
Bouteloua eriopoda – Pleuraphis jamesii Herbaceous Vegetation	*Bouteloua eriopoda* Herbaceous Alliance	24
Bouteloua gracilis – Pleuraphis jamesii Herbaceous Vegetation	*Bouteloua gracilis* Herbaceous Alliance	544
Bouteloua gracilis Herbaceous Vegetation	*Bouteloua gracilis* Herbaceous Alliance	261
Calamovilfa gigantea Desert Wash Shrub Herbaceous Vegetation	*Calamovilfa gigantea* Shrub Herbaceous Alliance	33
Ericameria nauseosa / Bouteloua gracilis Shrub Herbaceous Vegetation	*Ericameria nauseosa* Shrub Short Herbaceous Alliance	25
Opuntia whipplei – Sporobolus airoides Shrub Herbaceous Vegetation	No Alliance	1
Pleuraphis jamesii – Sporobolus airoides Herbaceous Vegetation	*Pleuraphis jamesii* Herbaceous Alliance	4,143
Salsola tragus Sand Dune Vegetation	No Alliance	101
Sporobolus airoides – Bouteloua gracilis Herbaceous Vegetation	*Sporobolus airoides* Sod Herbaceous Alliance	377
Sporobolus airoides Southern Plains Herbaceous Vegetation	No Alliance	125
Sporobolus coromandelianus Herbaceous Vegetation	Mapped < MMU	–
Sporobolus cryptandrus Great Basin Herbaceous Vegetation	*Sporobolus cryptandrus* Herbaceous Alliance	–
TOTAL	–	**16,680**

Grasslands support numerous wildlife species including 59 mammalian (A. Bridges, pers. comm. 2015) and 41 avian species (Holmes and Johnson 2010, 2012, 2014, 2016). Among the most charismatic mammalian species are pronghorn (*Antilocapra americana*), coyote (*Canis latrans*), and Gunnison's prairie dog (*Cynomys gunnisoni*; GPD). However, GPD represents the vertebrate species of greatest ecological importance and management concern, due to their potentially great influence grassland structure. In general, prairie dog presence is positively correlated with changing grassland structure from a more contiguous landscape of grass and shrub species to clumping of grassland plant species and exposed bare ground in areas within and at proximity to active GPD colonies (Bangert and Slobodchikoff 2000). Additionally, if large and stable GPD colonies (≥ 5,540 acres) are established within grasslands, PEFO would qualify as a potential reintroduction site for the U.S. Fish and Wildlife Service “endangered” black-footed ferret, *Mustela nigripes* (ADGF 2016a). Management efforts are underway to increase and hopefully stabilize the GPD population through translocating individuals from other Arizona populations, immunizing resident and translocated GPD against sylvatic plague, dusting for fleas to further reduce sylvatic plague transmission, and annual monitoring the GPD populations (Bridges 2016).

Refer to grassland birds’ assessment for specific information on occurrence and distribution information.

4.9.3. Indicators & Measures

Indicator
Grassland community extent

Measures
Grassland community extent

Through a geospatial vegetation analysis, Thomas et al. (2009a) identified 13 grassland communities encompassing ~16,640 ha. Increased drought due to climate change will likely result in changes to the current extent of grassland communities within the park.

Indicator
Native grassland species richness and composition

Measures
Native grassland species richness and composition

Hansen and Thomas (2006) identified 63 native grassland species occurring within the PEFO pre-2004 park boundary. No data within park expansion lands, but richness is expected to be similar. Climate change may affect species richness.

Indicator
Alien plant species occurrence

Measures
Alien plant species occurrence

Presently, there are 21 alien plant species known from the pre-2004 park boundary (Hansen and Thomas 2006). Thomas et al. (2009b) suggests distributions appear limited to road corridors and developed areas. Unfortunately, the park does not have an alien plant species monitoring program.

Such a program is required to both map distributions and manage existing alien species, as well as facilitate early detection and possible eradication of newly colonizing species.

Indicator
Ratio of native to alien plant species

Measures
Ratio of native to alien plant species

According to Hansen and Thomas (2006), the ratio of native to alien plant species is 63:21. This ratio was based upon a 12 years old dataset. This ratio may have changed with newly colonizing alien species.

Indicator
Vertebrate indicator species

Measures
Vertebrate indicator species

Gunnison's prairie dog and grassland birds are assessed in individual chapters. Refer to these chapters and their respective assessments.

Seven grassland and aridland bird indicator species occur at PEFO. This measure is assessed in the grassland bird chapter.

4.9.4. Data and Methods
The most comprehensive vegetation inventory and resultant highest resolution vegetation digital data layer was produced by Dr. Kathryn Thomas, U.S. Geological Survey (Hansen and Thomas 2006; Thomas et al. 2009a) and colleagues. Their work was based upon data collected from 186 relevé plots and 149 relevé plots (from 1996 and 2003, respectively) to characterize plant communities, including grasslands, within the 2003 park boundary. All communities were mapped within the 2003 park boundary including an approximately 1 km buffer outside this park boundary.

For the "Alliance" column, two categories do not represent actual vegetation alliances: (1) "No Alliance" indicates special categories created for PEFO, which do not fit within any of the currently defined alliances, and (2) "Mapped < MMU" indicates the vegetation type occurred in an area smaller than the minimum mapping unit (MMU; 0.5 ha) of the vegetation map (see Thomas et al. 2009a). Two grassland communities lack area estimates because the extent was smaller than the MMU of the vegetation map.

4.9.5. Reference Conditions
Invasive plant species occurrence information based upon Thomas et al. (2009a) and DeCoster and Swan (2016) may be useful to characterize reference conditions concerning the number and distributions of invasive plant species. Many invasive plant species are distributed along roadsides and within disturbed areas (Thomas et al. 2009b). However, the invasive forb *Salsola* spp. (Russian thistle; potentially three species may occur in the park) has been documented throughout grasslands

within the park's 2003 boundary. *Salsola* spp. likely occur within the expansion lands as well (K. Thomas, pers. com. 2017). While competition between *Salsola* spp. and native grasses species has been documented in the greenhouse (Allen 1982a, b), its competitive interaction with native grasses in the wild at PEFO is not known.

The condition of grasslands with a low population of GPD may be used as a baseline reference condition. The desired condition for the park is to maintain healthy GPD populations in all suitable grassland habitats (Bridges, pers. comm., 2018). This resultant grassland condition will be the long-term reference condition for this resource. Larger GPD populations will result in more open space/ patchy vegetation where these colonies occur. It is posited that the GPD modified landscape add a layer of complexity to western grasslands and will likely enhance habitat for a variety of animal species (Bangert and Slobodchikoff 2000).

4.9.6. Conditions and Trend

Resources are presently in an "unknown" condition. The trend is identified as "unchanging?" Aside from evidence of low but persistent occurrence of *Salsola* spp. and some invasive grasses within the grasslands, there is no other evidence to support the condition of grasslands as deteriorating. Conversely, there have been no assessments to quantify the health of grassland communities. However, grasslands (and other vegetation types) will experience increased stress due to altered precipitation patterns, increased drought conditions, destabilized sand sheets and shifting dunes and invasive species. Furthermore, with a large and stable population of GPD, which are known to modify grassland communities, this would shift GPD populated areas from contiguous grasslands to more patchily distributed grassland and shrubs.

4.9.7. Threats, Issues, and Data Gaps

Variable precipitation due to drought and rainfall patterns incongruent with grass species germination and establishment requirements (exacerbated by climate change) can adversely affect grassland health. Future scenario models examining predicted increased temperatures and drought conditions (Butterfield and Munson 2016; Bunting et al. 2017) and climatic variability in the Southwest (Gremer et al. 2015) intimate the loss of some cold-tolerant plant species and subsequent species turnover to warm tolerant plant species. During this predicted transition, vegetation cover may be reduced prompting the shift of sand sheets and dunes by aeolian processes and potentially further exacerbating the loss of vegetation cover. As the effects of climate change continue, stability of the sandy geological substrates upon which many of PEFO grassland communities may become destabilized. This will result in increased airborne sediment, new dune formation, and actively moving dunes such as occurs on the Navajo Nation to the north of PEFO. Research will be required to adequately model and ultimately monitor these processes. Additionally, development sensitivity/vulnerability models to identify important grassland species and those susceptible to the effects of climate change would highly useful in management planning. Climate change scenario models for characteristic Southwestern plant species are currently under development and will ultimately be available to compare and assess vulnerable plant species at PEFO (K. Thomas, pers. comm. 2017).

Alien plant species decrease diversity and reduce fitness of native plants and have a negative ripple effect on higher trophic levels within the ecosystem (Vilà et al. 2011). In general, alien plant species are predicted to adversely affect arid vegetation communities due to: (1) a shifting regional climatic regime to a shorter freeze-free season supporting warm-tolerant annual grasses in the long term; (2) increased drought conditions providing favorable conditions for invasive grass species expansion and colonization; and, (3) a longer fire season due to drier conditions, which increases fire probability in a given area and perpetuates a fire-invasive species feedback loop (Abatzoglou and Kolden 2011). These shifts will ultimately reduce native plant community diversity, result in many invasive species outcompeting native grassland species, and result in a vegetation community unsuitable for many vertebrate and invertebrate species. Within the 2003 park boundary, there are 21 nonnative invasive plant species representing ~25% of the known grassland species (Hansen and Thomas 2006). Of these, PEFO is spot treating for thistle (*Salsola* spp.) and puncture vine (*Tribulus terrestris*) in areas where the plants are encountered (A. Bridges, pers. com. 2017). Additionally, in 2016, the northern tamarisk beetle (*Diorhabda carinulata*) was detected within the park boundary; the park is qualitatively documenting the impacts of the beetle on tamarisk.

Presently, the NPS Southern Colorado Plateau Network, Inventory and Monitoring (SCPN I&M) Program (DeCoster and Swan 2011, 2016) is monitoring 60 upland grassland plots (within the pre-expansion areas of the park) to detect soil erosion, effects of climate change, and invasion by nonnative species. An additional and necessary component to this work should involve monitoring for invasive plant species through annual surveys of disturbed areas and along roadsides. These data will be required to manage for and monitor established nonnative invasive plant species populations, as well as serve as an early detection mechanism for newly colonizing invasive species. In some cases, it may be possible to eradicate newly established invasive plant species, but early detection is critical.

Another issue to consider will be monitoring the transition from a small discontiguous GPD population to a large population to quantify the changes on grassland diversity and composition. To address data gap, we recommend the establishment of a program to monitor the changes to grassland communities supporting GPD colonies. Methods for characterizing grasslands should follow and/or complement the methods applied by Bangert and Slobodchikoff (2000). Prior to the establishment of the desired conditions for black-footed ferret introduction (i.e., GPD colonies ≥ 5,540 acres), baseline conditions (i.e., grassland community composition and percent vegetation cover of suitable habitat presently without GPD colonies) should be quantified, and ecological indicators should be identified. For grasslands, the ecological condition should be examined and quantified prior to the establishment of the park's desired population size of GPD. Additionally, ecological indicator species should also be identified and monitored; for birds, the grassland birds' chapter lists several species that fit this criterion. Other indicator species should be identified and monitored. For grassland communities, the concordant percent vegetation cover should be measured and used as a baseline reference condition. Additionally, comparison to U.S. Department of Agriculture Natural Resource Conservation Service's Ecological Site Reference conditions will also be included in determining reference conditions for PEFO vegetation. Data from an on-going long-term monitoring program by SCPN I&M (DeCoster and Swan 2016) may be used to (1) characterize current conditions and use as a baseline condition; (2) model future conditions and trends due to climate change, invasive species; and, (3) monitor grassland changes associated with the potentially increasing GPD population. Once the GPD population is established, the corresponding indicator species and relevant ecological parameters should be quantified reflecting the changes to the ecosystem associated with a large GPD population.

Finally, a park-wide vegetation map of lands including both lands within the original 2003 boundary and the expansion lands will be required to most effectively manage both grasslands and other vegetation types. Vegetation (including grasslands) within the expansion lands have not been characterized and mapped; however, a request from the PEFO was submitted to SCPN I&M to complete the basic 12 surveys for the expansion lands to complete our inventories; however, this has not yet been approved. For consistency, we recommend methods compatible with the approach employed by Thomas et al. (2009a) and with the National Vegetation Classification system. The existing vegetation map and the expansion mapping should be made consistent across the original map boundaries.

4.9.8. Sources of Expertise

- Andy Bridges, Petrified Forest National Park, National Park Service
- Kathryn Thomas, Southwest Biological Science Center, U.S. Geological Survey, Tucson, Arizona

4.10. Alien Plant Species

4.10.1. Condition Summary

Condition assessment for alien plant species provided in Table 4.10-1.

Table 4.10-1. Condition assessment summary for nonnative alien plant species, Petrified Forest National Park, Arizona.

Indicator	Description	Condition Status/Trend	Summary
Alien plants (occurrence of nonnative alien plant species)	Four species with “high” and 12 with “medium” ranking (AWIPWG 2005) occur within the park.		While monitoring should be conducted for all 16 nonnative alien plant species, the four ranked "high" or "medium" by AWIPWG should be given priority if park resources are limited; early detection of newly arriving alien species should also be included in monitoring program. Park-wide inventories were conducted between 13 to 23 years ago (Hansen 1998; Hansen and Thomas 2006; Thomas et al. 2009a); more recent work conducted in upland grassland areas only (DeCoster and Swan 2011, 2016; DeCoster et al. 2012); thus, additional alien species may have become established in lowland areas. Condition, trend and confidence is “unknown.”
Change in Percent Cover of Alien Plant Species	Not known		No monitoring and/or geospatial data available depicting the change in percent cover of alien species over time. Condition, trend and confidence is “unknown.”
Distribution of Alien Species	Not known		No monitoring and/or geospatial data available depicting occurrence of alien plant species in disturbed and undisturbed areas. Condition, trend and confidence is “unknown.”
Efficacy of Tamarisk-Treated Areas	Not known		Efforts to control tamarisk have occurred in at least one area; however, geospatial distribution layers of tamarisk, the tamarisk treated area, and recovery was not produced. Condition, trend and confidence is “unknown.”

4.10.2. Background and Importance:

Invasive alien plant species decrease diversity and reduce fitness of native plants and have a negative ripple effect on higher trophic levels within ecosystems (Vilà et al. 2011). In general, alien plant species are predicted to adversely affect arid vegetation communities due to: (1) shifting regional climatic regime to a shorter freeze-free season supporting warm-tolerant annual grasses in the long term; (2) increased drought conditions providing favorable conditions for invasive grass species colonization and expansion; and, (3) a longer fire season due to drier conditions, which both increases fire likelihood and perpetuates a fire-invasive species feedback loop (Abatzoglou and Kolden 2011). These changes may ultimately reduce native plant community diversity resulting in a vegetation community unsuitable for many vertebrate and invertebrate species.

Future scenario models examined predicted increased temperatures and drought conditions (Butterfield and Munson 2016; Bunting et al. 2017) and climatic variability in the Southwest (Gremer et al. 2015). Their results suggest the PEFO environment under future climate change scenarios will be less favorable climate conditions for some cold-tolerant plant species and more favorable climate conditions for some warm tolerant plant species. These changing climatic conditions may increase opportunities for alien species colonization and establishment.

4.10.3. Data and Methods

Field studies by Hansen (1998), Hansen and Thomas (2006), Thomas et al. (2009a), DeCoster and Swan (2011, 2016) and DeCoster et al. (2012) were used to compile a list of 67 invasive alien plant species (Appendix F) documented at PEFO. Of these, 19 species were ranked based upon their threat to native ecosystems (Arizona Wildlands Invasive Plants Working Group, AWIPWG; AWIPWG 2005; Table 4.10-2) including four considered a "high" threat to native ecosystems, 12 placed in the "medium" category, and three ranked as a "low" threat to native ecosystems. Additionally, two species were evaluated, *Tribulus terrestris* (puncture vine) and *Verbascum thapsus* (mullein), but information was inadequate to place them in one of the three threat categories. The remaining 46 species listed in Appendix F were not evaluated by the AWIPWG and may include species that are high and medium threat.

Table 4.10-2. Twenty-one alien plant species known to occur within Petrified Forest National Park, Arizona and evaluated by the Arizona Wildlands Invasive Plants Working Group (AWIPWG). "Scientific name," species' "Authority" and "Common Name" are provided.

Scientific Name	Authority	Common Name	Authors[1]	Rank[2]
Bromus rubens	L.	red brome	1, 2, 6	1
Bromus tectorum	L.	cheat grass	1, 2, 3, 4, 5, 6	1
Elaeagnus angustifolia	L.	Russian olive	1, 6	1
Tamarix chinensis	Lour.	five-stamen tamarix	1, 6	1
Alhagi maurorum	Medik.	camelthorn	1	2
Bromus inermis	Leyss.	smooth brome	2	2
Carduus nutans	L.	nodding plumeless thistle	4	2
Convolvulus arvensis	L.	field bindweed	1	2
Cynodon dactylon	(L.) Pers.	bermuda grass	1, 2	2
Erodium cicutarium[3]	(L.) L'Hér. ex Aiton	redstem stork's bill	1, 4, 5, 6	2
Melilotus officinalis	(L.) Lam.	sweet clover	1	2
Salsola collina	Pall.	slender Russian thistle	5	2
Salsola tragus[4]	L.	prickly Russian thistle	3, 5, 6	2
Sonchus asper	(L.) Hill	spiny sowthistle	1, 6	2
Sorghum halepense	(L.) Pers.	Johnsongrass	1, 2	2
Ulmus pumila	L.	Siberian elm	1	2
Cirsium vulgare	(Savi) Ten.	bull thistle	1	3
Echinochloa crus-galli	(L.) Beauv.	barnyard grass	2	3
Lolium perenne	L.	perennial ryegrass	1, 2	3
Tribulus terrestris	L.	puncture vine	1	4
Verbascum Thapsus	L.	mullein	1	4

[1] "Authors" refers to the source documenting the species' occurrence Hansen 1998 (1), Hansen and Thomas 2006 (2), DeCoster and Swan 2011 (3), DeCoster et al. 2012 (4), DeCoster and Swan 2016 (5), and Thomas et al. 2009 (6).

[2] "Rank" represents threat to native ecological systems as determined by AWIPWG (2005). These categories are high (1), medium (2), low (3), and, evaluated but not ranked (4). Definitions for each category are provided below. Species are listed alphabetically within each AWIPWG category.

[3] May represent a native invasive species (Hansen 1998).

[4] Hrusa and Gaskin (2008) suggest this species represents a three species (S. tragus, S. gobicola, and S. paulsenii) complex. AWIPWG (2005) evaluated Arizona alien plant species and placed them in the following four ecological severity categories. (1) High: Species had severe impacts on ecosystems, plant and animal communities, and vegetation structure; invasiveness was conducive to moderate to high rates of dispersal and establishment; and, species were typically widely distributed, both among and within ecosystems/communities. (2) Medium: Species had substantial and apparent impacts on ecosystems, plant and animal communities, and vegetation structure; invasiveness was conducive to moderate to high rates of dispersal, often enhanced by disturbance; and, ecological amplitude (diversity of ecosystems/communities) and distribution (within an ecosystem/community) ranged from limited to widespread. (3) Low: Species had minor yet detectable ecological impacts; invasiveness resulted in low to moderate rates of invasion; and, ecological amplitude and distribution was generally limited, but the species could be problematic locally. (4) Evaluated but not listed: Current information was inadequate to categorize the species in one of the above three categories.

4.10.4. Indicators & Measures

Indicator
Alteration of Native Plant Communities

Measures
Alien Plants with High/Medium Invasiveness Ranking

Although there have been surveys to identify alien plant species within the park, there have been no efforts to monitor or quantify the occurrence and distribution of alien plant species. There are four "high" and 12 "medium" ranked species based upon AWIPWG (2005). High ranked species pose severe ecological impacts, are conducive to moderate to high rates of dispersal and establishment, and usually widely distributed, while medium-ranked species have substantial and apparent ecological impacts, conducive to moderate to high rates of dispersal, often enhanced by disturbance, and ecological amplitude and distribution range from limited to widespread (AWIPWG 2005). However, we do not know their current distribution, nor do we know the threat these species pose. Riparian restoration efforts to remove *T. chinensis* has been underway since the mid-1980s, but the coverage of *T. chinensis* and the area restored has not been quantified. Thus, we do not have the information to assess this indicator and measure.

Indicato
Change in Percent Cover of Alien Plant Species

Measures
Change in Percent Cover of Alien Plant Species

There are no geospatial data available depicting the cover of alien plant species over time. Thus, we do not have the ability to determine the extent to which percent cover of alien species has changed over time.

Indicator
Distribution of Alien Plant Species

Measures
Percent cover of alien plant species in disturbed and undisturbed areas

As there are no geospatial data available depicting cover of alien plant species within the park, we do not have the ability to determine the percent cover of alien plant species in disturbed and undisturbed areas.

Indicator
Recovery of Treated Areas

Measures
Area Restored due to Cutting and Treating Tamarisk

While there have been efforts to cut and treat tamarisk within at least one area within the park, geospatial data of the distribution of tamarisk, the tamarisk treated area, and recovery was not produced. Thus, it is not possible to access this indicator and measure.

4.10.5. Reference Conditions

The species list provided in Table 4.10-2 and Appendix F may be used to characterize reference conditions concerning the presence of these species. Four "level 1" species (*B. rubens B. tectorum, E. angustifolia,* and *T. chinensis*) and 12 "level 2" species occur within PEFO (refer to Table 4.10-2 and Appendix F). Currently, most alien plant species are distributed along roadways (Hansen 1998, Thomas et al. 2009b), riparian areas, sensitive recreation sites (Hansen 1998), and within disturbed areas (Thomas et al. 2009b); however, a park-wide inventory has yet to occur. This information will be required to establish reference conditions for the park.

In general, information compiled from Hansen (1998), Hansen and Thomas (2006), Thomas et al. (2009a), DeCoster and Swan (2011, 2016) and DeCoster et al. (2012) may be useful in developing coarse distributions of certain alien plant species.

4.10.6. Conditions and Trend

Occurrence of nonnative alien plant species: Four species with "high" and 12 with "medium" ranking (AWIPWG 2005) occur within the park. However, a total of 16 alien plant species have been documented. While monitoring should be employed for all 16 nonnative alien plant species, the four with an invasiveness ranking "high" or "medium" by AWIPWG should be given priority if park resources are limited. Park-wide inventories were conducted between 13 to 23 years ago (Hansen 1998; Hansen and Thomas 2006; Thomas et al. 2009a), while more recent work conducted in upland grassland areas only (DeCoster and Swan 2011, 2016; DeCoster et al. 2012). Additional alien plant species may have become established in lowland areas over the past 10 years. Thus, Condition, trend and confidence is "unknown."

Change in alien plant species percent cover: No monitoring and/or geospatial data available depicting the change in percent cover of alien species over time. Therefore, condition, trend and confidence is "unknown."

Distribution of alien plant species: No monitoring and/or geospatial data available depicting occurrence of alien plant species in disturbed and undisturbed areas. Ergo, condition, trend and confidence is "unknown."

Efficacy of tamarisk treated areas: Efforts to control tamarisk have occurred in at least one area; however, no geospatial distribution modeling of tamarisk has been conducted. Thus, condition, trend and confidence is "unknown" – as the tamarisk treated area extent is not known, nor has the current condition of the treated areas been assessed.

4.10.7. Threats, Issues, and Data Gaps

In general, many alien plant species are distributed along roadways (Hansen 1998, Thomas et al. 2009b), riparian areas, sensitive recreation sites (Hansen 1998), and within disturbed areas (Thomas et al. 2009b). A park-wide survey should be undertaken to revisit these sites, identify the species present, and map their spatial distributions. Additionally, the invasive forb *Salsola* spp. has been documented throughout grasslands within the park's pre-2004 boundary (DeCoster and Swan 2011, DeCoster and Swan 2016, Thomas et al. 2009) and likely occurs within the expansion lands as well (K. Thomas, pers. com. 2017). While competition between *Salsola* spp. and native grasses species has been documented in the greenhouse (Allen 1982a, b), its competitive interaction with native grasses in the wild at PEFO is not known. To best manage and protect PEFO grasslands, the interaction of *Salsola* spp. and native grasses species should be investigated.

None of the 67 known invasive alien plant species are presently being managed by PEFO. The current distributions of any of these species within park boundaries is unknown, and no means of prioritizing management or monitoring strategies for these species is established. Presently, only tamarisk, a species ranked as "high" by AWIPWG (2005), is being sporadically monitored. Observations on tamarisk began in April 2016 when herbivory by *Diorhabda carinulata* Desbrochers, 1870, a beetle species released for tamarisk biocontrol along the upper Colorado River corridor, was detected (A. Bridges, pers. com 2017).

A program for monitoring and managing the 16 species ranked as "high" and "medium" threat by the AWIPWG (and others identified by park officials), as well as early detection of newly colonizing alien plant species is urgently needed. As mentioned above, changing climate and the likely continued introduction of other alien plant species will continue to threaten ecological integrity, as well as the ability for these ecosystems to function optimally and support native plant and animal species.

Distributions of invasive alien species within the park boundary are not well characterized. Baseline and testable distribution maps of management concern species may be developed using Hansen (1998), Hansen and Thomas (2006), Thomas et al. (2009a), DeCoster and Swan (2011, 2016) and DeCoster et al. (2012). These interpolative geospatial layers of distributions may then be ground-truthed with field campaigns and refined accordingly.

4.10.8. Sources of Expertise

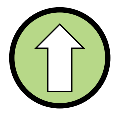
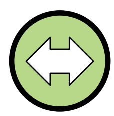
- Andy Bridges, Petrified Forest National Park, National Park Service
- Kathryn Thomas, Southwest Biological Science Center, U.S. Geological Survey, Tucson, Arizona

4.11. Gunnison's Prairie Dog

4.11.1. Condition Summary

Condition assessment for Gunnison's prairie dog provided in Table 4.11-1.

Table 4.11-1. Condition assessment summary of Gunnison's prairie dog, Petrified Forest National Park, Arizona.

Indicator	Description	Condition Status/Trend	Summary
Colony extent	13 colonies comprising ~340 acres (Bridges 2016)		Although the GPD population has fluctuated since 1997 (and likely before), colony numbers are likely to increase given active management strategies to promote a healthy increasing population, thus condition is considered "good" and trend is "improving." Population has been largely monitored since 1997, so confidence is "high."
Available suitable habitat	185,828 acres (Bridges 2016)		Changes in precipitation patterns due to climate change may ultimately result in the extent of suitable habitat. As amount of available habitat has been largely unchanged and the inventory completed, condition is "good," trend is "unchanging" and confidence "high."

4.11.2. Background and Importance

Gunnison's prairie dogs (*Cynomys gunnisoni* (Baird, 1855), GPD) are burrowing rodents of the squirrel family (Sciuridae) and occur from central Colorado and central Arizona through southeastern Utah and most of the northwestern half of New Mexico (Pizzimenti and Hoffmann 1973; IUCN 2016). Throughout its range, GPD establishes comparatively small colonies from 50–100 individuals (Pizzimenti and Hoffmann 1973). As with all *Cynomys* spp., GPD populations are susceptible to periodic outbreaks of sylvatic plague. When a colony is exposed to sylvatic plague (caused by the bacteria, *Yersinia pestis* (Lehmann and Neumann, 1896)), 100% mortality often results (Hoogland 1999, 2006). Population crashes associated with periodic plague outbreaks have been documented on PEFO (Hoogland 1999).

Based upon results from a study conducted on PEFO, GPD were identified as keystone species and ecosystem engineers (Bangert and Slobodchikoff 2000; Bangert and Slobodchikoff 2006). Bangert and Slobodchikoff (2000) suggest this species plays a "keystone" role by increasing habitat heterogeneity at a landscape scale. Both between-habitat (beta) and regional (gamma) diversity of ground-dwelling arthropods is higher in active prairie dog towns than in inactive prairie dog towns, as well as grassland without prairie dog activity (Bangert and Slobodchikoff 2006). Additionally, the presence of active prairie dog (*Cynomys* spp.) communities influences the structure of vertebrate communities and results in higher avian richness including species of conservation concern (Lomolino and Smith 2003; Smith and Lomolino 2004).

By having robust and stable GPD populations, PEFO could be considered as a potential reintroduction site for the U.S. Fish and Wildlife Service "endangered" black-footed ferret; *Mustela nigripes* (Audubon and Bachman, 1851). In Arizona, the minimum acreage required for black-footed ferret reintroduction is 5,540 acres; the acreage of multiple active colonies within 9 km distance may be used to meet this requirement (AGFD 2016a). Davis and Wilson (2015) identified 17.9 acres supporting active prairie dog towns, while Bridges (2016) identified ~340 acres with active GPD colonies. While PEFO presently does not meet the minimum GPD inhabited acreage requirements for black-footed ferret introduction, there is 185,828 acres of suitable GPD habitat (Bridges 2016).

In 2016, PEFO launched a program to protect and increase GPD populations including: (1) a park-wide effort to identify and map all GPD towns; (2) apply pesticide in an attempt to kill fleas and reduce sylvatic plague transmission; (3) oral plague vaccine laced baits to immunize populations against plague; (4) translocation of healthy individuals from other locations into the park to increase populations; and, (5) annual monitor of GPD populations to gauge changes to population size, density, and overall colony health.

4.11.3. Indicators and Measures

Indicator
Colony extent

Measures
Colony extent

Thirteen GPD colonies comprising ~340 acres occur in PEFO (Bridges 2016). Although the GPD population has fluctuated since 1997 (and likely before), colony numbers are likely to increase given active management strategies to promote a healthy increasing population.

Indicator
Available suitable habitat

Measures
Available suitable habitat

Available suitable GPD habitat is approximately 185,828 acres (Bridges 2016). It is possible this acreage may change over time due to climate change induced changes in precipitation patterns.

4.11.4. Data and Methods

Over the past 20 years, occupied GPD suitable habitat has fluctuated. From 1997 to 2007, 16 prairie dog colonies representing a maximum of ~862 acres of occupied habitat were mapped (Bridges 2016). Efforts conducted in 2016 associated with safeguarding GPD populations and improving suitability for black-footed ferret reintroduction include the following: (a) 13 of 15 known GPD colonies were active comprising 340 acres (Table 4.11-2); (b) treated all 13 GPD colonies (2,720 GPD burrows and other holes used by burrowing mammals) with the pesticide DeltaDust

(Deltamethrin 0.05%); (c) deployed baits containing the RCN-F1/V307 sylvatic plague vaccine at 10 GPD colonies (3,629 baits at 1,136 burrows); (d) translocated 50 individuals from Flagstaff to the park; and, (e) completed the first year (2016) of monitoring of the recently translocated animals.

Table 4.11-2. Name, location, extent (in acres), number of burrows (# Burrows), and burrow density (burrows/acre) of active GPD colonies from Bridges (2016). Number of burrows and burrow density reflect active fossorial habitat. Location represents the approximate centroid of the GPD colony in in UTM, NAD 83, Zone 12S.

Name	Location	Extent	# Burrows	Burrow Density/ Acre
180	605787, 3849238	Unk	Unk	Unk
9-Mile Wash	614887, 3870778	8.00	36	4.50
Doubtful East	617769, 3869012	22.00	196	8.91
Doubtful West	616756, 3869786	25.00	301	12.00
Horse Barn	601062, 3854106	14.00	634	45.30
House	612052, 3881222	80.00	212	2.70
Lone Tree	611234, 3865699	32.00	306	9.60
Moria	604743, 3860295	75.00	450	6.00
Newspaper Rock	610057, 3869889	40.00	288	7.20
North Tank	625674, 3881957	18.00	59	3.30
Shipping Pasture	624993, 3877316,	9.00	157	17.40
Sorrel Horse	623498, 3870090	17.00	81	4.80
Twin Buttes	611174, 3859754	0.03	6	6.00

4.11.5. Reference Conditions

Reference conditions are difficult to establish. Since studies on PEFO GPDs were first undertaken, researchers have documented 100% mortalities at some prairie dog colonies due to sylvatic plague outbreaks. We suggest the desired reference condition would be stable and growing GPD populations free from periodic plague-driven population crashes. Once the park has completed the GPD sylvatic plague vaccination project at all known prairie dog towns, this will become an important reference point to begin future monitoring.

Establishing an area of at least 5,540 acres of occupied GPD habitat (the baseline requirement for black-footed ferret reintroduction) will be a second important reference point for monitoring. PEFO has developed a program to safeguard and bolster GPD populations may ultimately provide the park with this opportunity.

Collectively, higher landscape-scale habitat heterogeneity, promote higher diversity of ground-dwelling arthropods and potentially result in higher diversity of vertebrate species will be another long-term ecological condition for the park. Collecting the baseline data to characterize habitat heterogeneity, as well as conducting inventory data on ground-dwelling arthropods and vertebrates will be important for establishing the baseline for future monitoring.

4.11.6. Conditions and Trend

If population crashes associated with sylvatic plague outbreaks can be prevented, the desired condition, "stable" and "increasing" populations will likely result. If populations increase to ultimately encompass at least 5,540 acres, park officials may petition to have PEFO evaluated as a potential black-footed ferret reintroduction site.

4.11.7. Threats, Issues, and Data Gaps

The greatest threat to GPD is populations crashes associated with sylvatic plague outbreaks. PEFO is taking aggressive measures to address this threat while advancing a reintroduction program to further bolster the GPD population. In addition to their current efforts, we recommend year-round disease monitoring of GPD colonies for early detection. The protocol for safely collecting samples of prairie dog blood, tissue and carcasses, as well sympatric rodents, rabbits, mammalian mesocarnivores (e.g., coyotes, foxes, and badgers) and fleas (via burrow swabbing) is provided in Appendix E, Black-footed ferret Management Plan (ADGF 2016b).

Information gaps include lack of annual monitoring data of all GPD towns, as well as other ecological variables and community information associated with GPD colonies. Data gaps include the following: (i) high-resolution coordinate data to accurately estimate the geospatial extent of each GPD colony; (ii) GIS-derived maps of the geospatial extent of each colony; (iii) documentation of mortalities encountered derived from monitoring data; (iv) annual census data of populations for each GPD colony; (v) landscape structure variables employing methods similar to Bangert and Slobodchikoff (2000) for monitoring landscape heterogeneity; and, (vi) inventory data on both ground-dwelling arthropods and vertebrates. The development of a robust multi-year dataset will enable managers and researchers to examine population trends, determine population responses to sylvatic plague vaccines and pesticide dusting, obtain important information for characterizing PEFO GPD as keystone species, and ascertain whether PEFO has accrued the required acreage for consideration as a black-footed ferret reintroduction site.

4.11.8. Sources of Expertise

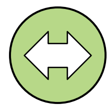
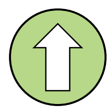
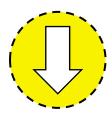
- Andy Bridges, Petrified Forest National Park.
- Holly Hicks, Arizona Game and Fish Department, Phoenix, Arizona.
- Con Slobodchikoff, Northern Arizona University, Flagstaff.

4.12. Grasslands Birds

4.12.1. Condition Summary

Condition summary for grassland birds provided in Table 4.12-1.

Table 4.12-1. Condition assessment summary for grassland birds, Petrified Forest National Park, Arizona.

Indicator	Description	Condition Status/Trend	Summary
Habitat extent	13 grassland communities encompassing ~16,640 ha (Thomas et al. 2009a)		No data within park expansion lands; as the landscape is similar in the pre-expansion boundary; condition is “good,” and trend currently “unchanging,” although confidence is “moderate” as no surveys in expansion lands have been conducted.
Native grassland bird species richness and composition	41 grassland bird species (Holmes and Johnson 2010, 2012, 2014, 2016)		No data within park expansion lands, but richness and composition is expected to be similar. Condition is “good,” and trend currently “unchanging,” although confidence is “moderate” as no surveys in expansion lands have been conducted.
Indicator species	Seven indicator species occur within PEFO; all were identified as in decline.		No data within park expansion lands, but the condition of indicator species is expected to be similar. As indicator species are in decline, condition warrants “moderate concern,” and trend is “deteriorating,” confidence is “moderate” as no surveys in expansion lands have been conducted.

4.12.2. Background and Importance

Grassland birds are one of the fastest declining bird groups in the U.S. (NABCI 2011). While many grassland bird species are capable of coexisting in human use areas, in most cases, grassland bird populations are healthiest in minimally disturbed grasslands. Today, only 13% of U.S. grasslands occur on federal lands and less than 2% of those lands are designated for conservation (NABCI 2011).

In PEFO, grasslands are the most widespread and considered among the most important vegetation communities environmentally. Within the pre-2004 park boundary, grassland communities comprised nearly 70% of the park’s vegetation communities (Thomas et al. 2009a), at least 13 different grassland associations (Thomas et al. 2009a), and 84 grass species (Hansen and Thomas 2006). Refer to the Grasslands Chapter for more information. Given the extensive coverage of this vegetation type within the park boundary, and that most parklands have been minimally impacted by recent human activities, park officials have a unique opportunity to both potentially enhance and further protect these habitats to maximize the potential to support grassland breeding birds.

4.12.3. Indicators & Measures

Indicator
Habitat extent

Measures
Habitat extent

Grassland bird habitat consists of 13 grassland communities encompassing ~16,640 ha (Thomas et al. 2009a). The extent of grasslands in the post-2004 park expansion boundary has not been estimated. Thus, the area available to grassland birds is probably larger.

Indicator
Native grassland bird species richness and composition

Measures
Native grassland bird species richness and composition

At least 41 grassland bird species are known to occur within PEFO (Holmes and Johnson 2010, 2012, 2014, 2016). No work has been conducted outside of the pre-2004 park boundary, but richness is expected to be similar.

Indicator
Indicator species

Measures
Indicator species

Seven grassland bird indicator species occur within PEFO. The Cassin's sparrow, vesper sparrow, lark bunting, eastern meadowlark, and western meadowlark are considered grassland indicator species and identified as significantly declining (NABCI 2014). Additionally, the scaled quail and black-throated sparrow are considered aridlands indicator species and are also significantly declining (NABCI 2014.). Specifically, scaled quail, detected each of the four years of monitoring at PEFO, has the second highest declining trend (−3.47) in the aridlands indicator (Holmes and Johnson 2016). Upon examining the total number of species detected weighted by sampling effort, the black-throated sparrow was the most abundant species across all four years (Holmes and Johnson 2010, 2012, 2014, 2016; refer to Appendix G). The lead authors of this work have not conducted multi-year dataset to date, thus trends regarding the status of indicator species are not yet available.

4.12.4. Data and Methods

Since 2007, avian ecologists with the Colorado Plateau Research Station, Northern Arizona University, in collaboration with the NPS Southern Colorado Plateau Inventory and Monitoring Network (SCPIMN), have conducted systematic surveys for grassland breeding birds and grassland bird habitat (Figure 4.12-1; Holmes and Johnson 2010, 2012, 2014, 2016). Through their work, they identified 41 bird species (Table 4.12-2) and sampled seven ecological indicator species (refer to Reference Conditions section below). Refer to Holmes et al. (2014) for a description of their sampling protocol.

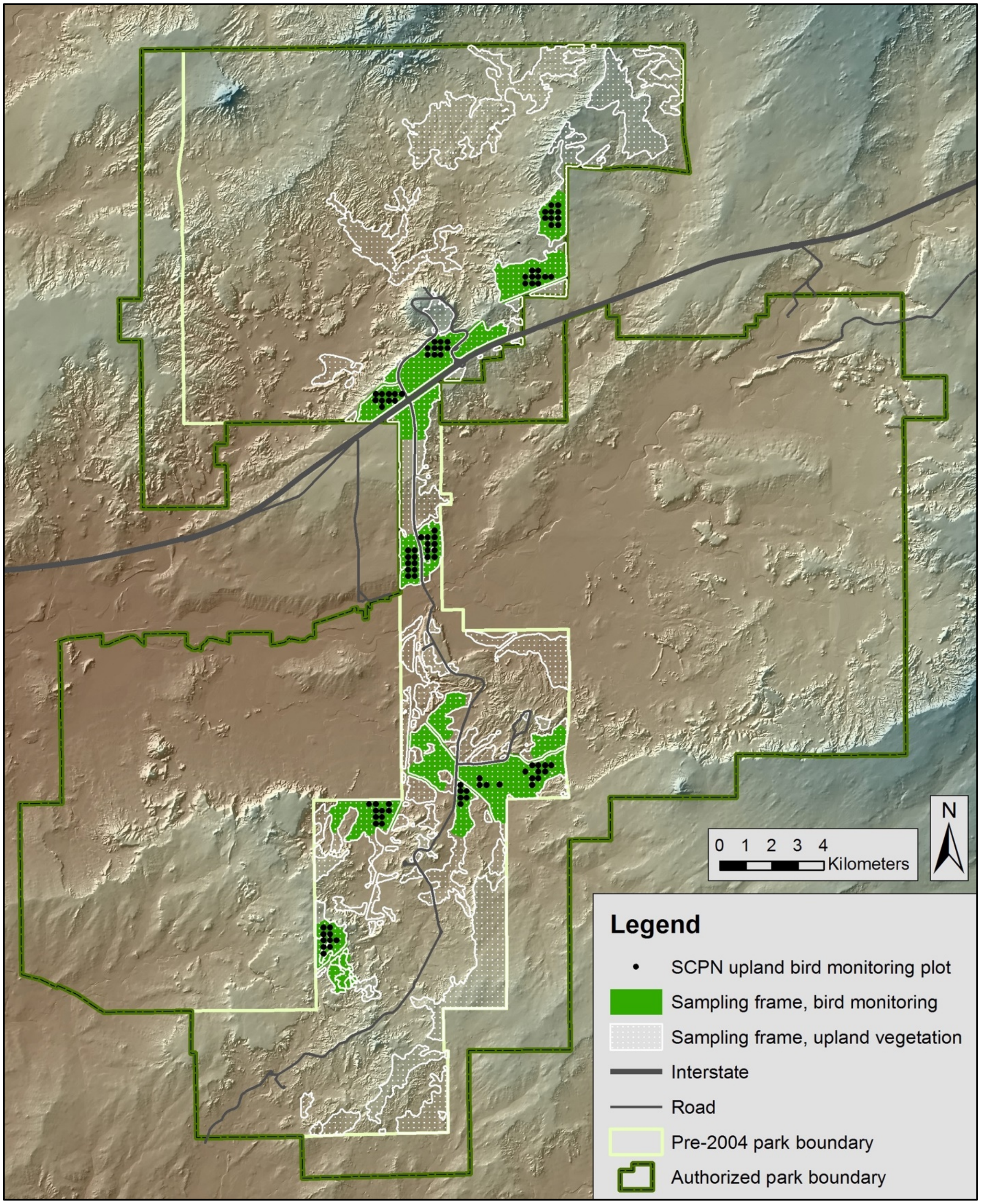


Figure 4.12-1. Grassland bird monitoring sampling frame with 10 clusters of bird monitoring plots; and upland vegetation monitoring sampling frame in Petrified Forest National Park, AZ (Holmes and Johnson 2010, 2012, 2014, 2016).

Table 4.12-2. The 41 grassland bird species detected in Petrified Forest National Park, Arizona during breeding season standardized bird counts. Compiled from Holmes and Johnson (2010, 2012, 2014, 2016).

Order	Family	Common Name	Scientific Name	Authority
Accipitriformes	Accipitridae	Cooper's hawk	*Accipiter cooperii*	(Bonaparte, 1828)
	Accipitridae	golden eagle	*Aquila chrysaetos*	(Linnaeus, 1758)
	Accipitridae	northern harrier	*Circus cyaneus*	(Linnaeus, 1766)
	Accipitridae	red-tailed hawk	*Buteo jamaicensis*	(Gmelin, 1788)
	Cathartidae	turkey vulture	*Cathartes aura*	(Linnaeus, 1758)
Falconiformes	Falconidae	American kestrel	*Falco sparverius*	Linnaeus, 1758
	Falconidae	prairie falcon	*Falco mexicanus*	Schlegel, 1850
Galliformes	Odontophoridae	scaled quail	*Callipepla squamata*	(Vigors, 1830)
Columbiformes	Columbidae	mourning dove	*Zenaida macroura*	(Linnaeus, 1758)
Strigiformes	Strigidae	burrowing owl	*Athene cunicularia*	(Molina, 1782)
Caprimulgiformes	Caprimulgidae	common nighthawk	*Chordeiles minor*	(Forster, 1771)
Apodiformes	Apodidae	white-throated swift	*Aeronautes saxatalis*	(Woodhouse, 1853)
	Trochilidae	black-chinned hummingbird	*Archilochus alexandri*	(Bourcier and Mulsant, 1846)
	Trochilidae	broad-tailed hummingbird	*Selasphorus platycercus*	(Swainson, 1827)
Passeriformes	Alaudidae	horned lark	*Eremophila alpestris*	(Linnaeus, 1758)
	Corvidae	common raven	*Corvus corax*	Linnaeus, 1758
	Emberizidae	black-throated sparrow	*Amphispiza bilineata*	(Cassin, 1850)
	Emberizidae	Brewer's sparrow	*Spizella breweri*	Cassin, 1856
	Emberizidae	Cassin's sparrow	*Peucaea cassinii*	(Woodhouse, 1852)
	Emberizidae	lark bunting	*Calamospiza melanocorys*	Stejneger, 1885
	Emberizidae	lark sparrow	*Chondestes grammacus*	(Say, 1822)
	Emberizidae	vesper sparrow	*Pooecetes gramineus*	(Gmelin, 1789)
	Fringillidae	house finch	*Haemorhous mexicanus*	(Statius Müller, 1776)
	Hirundinidae	barn swallow	*Hirundo rustica*	Linnaeus, 1758

Table 4.12-2 (continued). The 41 grassland bird species detected in Petrified Forest National Park, Arizona during breeding season standardized bird counts. Compiled from Holmes and Johnson (2010, 2012, 2014, 2016).

Order	Family	Common Name	Scientific Name	Authority
Passeriformes (continued)	Hirundinidae	cliff swallow	*Petrochelidon pyrrhonota*	(Vieillot, 1817)
	Hirundinidae	violet-green swallow	*Tachycineta thalassina*	(Swainson, 1827)
	Icteridae	brown-headed cowbird	*Molothrus ater*	(Boddaert, 1783)
	Icteridae	eastern meadowlark	*Sturnella magna*	(Linnaeus, 1758)
Passiformes (cont'd)	Icteridae	western meadowlark	*Sturnella neglecta*	Audubon, 1844
	Icteridae	yellow-headed blackbird	*Xanthocephalus*	(Bonaparte, 1826)
	Laniidae	loggerhead shrike	*Lanius ludovicianus*	Linnaeus, 1766
	Mimidae	Bendire's thrasher	*Toxostoma bendirei*	(Coues, 1873)
	Mimidae	northern mockingbird	*Mimus polyglottos*	(Linnaeus, 1758)
	Parulidae	yellow-rumped warbler	*Setophaga coronata*	(Linnaeus, 1766)
	Passeridae	house sparrow	*Passer domesticus*	(Linnaeus, 1758)
	Troglodytidae	rock wren	*Salpinctes obsoletus*	(Say, 1822)
	Tyrannidae	ash-throated flycatcher	*Myiarchus cinerascens*	(Lawrence, 1851)
	Tyrannidae	Cassin's kingbird	*Tyrannus vociferans*	Swainson, 1826
	Tyrannidae	gray flycatcher	*Empidonax wrightii*	Baird, 1858
	Tyrannidae	Say's phoebe	*Sayornis saya*	(Bonaparte, 1825)
	Tyrannidae	western kingbird	*Tyrannus verticalis*	Say, 1923

4.12.5. Reference Conditions

A four-year dataset of PEFO grassland breeding species occurrence and abundance data has been collected, which includes habitat/vegetation data collected from each bird study plot (Holmes and Johnson 2010, 2012, 2014, 2016). These data represent the most robust dataset for vertebrate species collected in the park and should be considered an important baseline (or reference condition) for monitoring future trends. Two to three species (horned lark, black-throated sparrow and eastern meadowlark) were the most abundant across all years representing 65.1 to 76.2 % of all detections (Table 4.12-3). Importantly, all four years, the horned lark was the most commonly detected species ranging from 52.96% (2007), 52.59% (2009), 55.30% (2012), and 30.31% (2015) of all species detections.

Table 4.12-3. Summaries of the most common species for year for 2007, 2009, 2012 and 2015 (Holmes and Johnson 2010, 2012, 2014, 2016) for Petrified Forest National Park, Arizona. Number of variable circular plots (#VCP), species (#Species) and individuals (#Individuals) and the percentage of the two to three most common species are provided.

Year	#VCP	# Species	# Individuals	Most Common Species	% Most Common Species
2007	300	23	3,025	horned lark, black-throated sparrow	65.09
2009	200	29	1,388	horned lark, black-throated sparrow	74.06
2012	300	27	1,322	horned lark, black-throated sparrow	76.18
2015	200	22	1,597	horned lark, black-throated sparrow, eastern meadowlark	75.39

Additionally, an on-going vegetation monitoring program developed by the NPS SCPIMN (DeCoster et al. 2012; DeCoster and Swan 2016) was established to evaluate upland grassland communities. They established 10 and 20 study plots within the Clayey Fan and Sandy Loam ecological sites, respectively. Through this program, NPS SCPN I&M characterized PEFO grasslands primarily by *Bouteloua eriopoda* and *Muhlenbergia porteri*, as well as other widespread grass species including *Bouteloua gracilis, Achnatherum hymenoides* and *Pleuraphis jamesii*. While other shrub and succulent species occur, grassland cover predominates (DeCoster et al. 2012). Through their efforts, DeCoster and Swan (2016) suggest their sampling sites were examples of diverse and relatively undisturbed grassland.

The occurrence and distributions of alien plant species may degrade grassland bird breeding habitat, and thus may have a negative cascading effect on these populations. Occurrence information based upon Thomas et al. (2009a) and DeCoster and Swan (2016) may be useful to characterize reference conditions concerning the number and distributions of alien plant species. Presently, most alien plant species distributions on PEFO occur along roadsides and within disturbed areas (Thomas et al. 2009b). However, the alien forb, *Salsola* spp. (potentially three species may occur in the park), has been documented throughout grasslands within the park's 2003 boundary. *Salsola* spp. likely occurs within the expansion lands as well (K. Thomas, pers. com. 2017). While competition between

Salsola spp. and native grasses species has been documented in greenhouse experiments (Allen 1982a, b), its competitive interaction with native grasses in the wild at PEFO is not known. This interaction and the associated negative effects on native grasses should be considered in any future monitoring to gauge and better manage both native grasslands and grassland breeding bird habitat.

Finally, PEFO grasslands currently support a relatively low population of Gunnison's prairie dog (GPD), which may be used as a baseline reference condition. As a larger GPD population (≥ 5,540 acres of inhabited area) is a desired condition for the park (Bridges 2016), the resultant grassland conditions will likely become the new reference condition. Larger GPD populations will result in more open space/ patchy vegetation where colonies occur and will overall promote higher heterogeneity within these grassland habitats. Bangert and Slobodchikoff (2000) suggested the GPD modified landscape at PEFO likely enhance habitat for a variety of animal species. In other American West grassland communities (where the black-tailed prairie dog occurs), Augustine and Baker (2013) reported that three bird species of conservation concern, one game bird species, and nine other vertebrate species had higher densities in sites with prairie dog colonies when compared to sites without colonies. Thus, it seems reasonable to suggest similar long-term ecological benefits may result with higher GPD densities at PEFO.

The NPS SCPIMN grassland data, the CPRS grassland breeding bird data, and monitoring data of lands with current GPD colonies, as well as those areas targeted as future GPD reintroduction sites, may be used to establish a set of reference conditions for grasslands and grassland breeding bird habitat. These conditions will useful in: (1) characterizing past/current conditions; (2) modeling future conditions and trends due to climate change and alien plant species introductions and range expansions; and, (3) monitoring the responses of both grasslands and grassland breeding birds associated with the potentially increasing park-wide population densities of GPD.

4.12.6. Conditions and Trend

Resources are presently in "good" condition with the trend identified as "unchanging?" Aside from evidence of low but persistent occurrence of *Salsola* spp. and some alien grass species within the grasslands, there is no current evidence to suggest conditions of grassland breeding birds, and/or the grassland habitats they require, are in decline. However, grasslands (and other vegetation types) will experience increased stress due to altered precipitation patterns, increased drought conditions, destabilized sand sheets and shifting dunes and alien plant species. Furthermore, with a large and stable population of GPD, which are known to modify grassland communities, this could shift GPD populated areas from contiguous grasslands to more patchily distributed grassland and herbaceous shrub species. These impending environmental and community changes may affect both grassland habitat and grassland breeding bird populations; however, the long-term effects are hypothesized to be beneficial.

4.12.7. Threats, Issues, and Data Gaps

Variable precipitation due to drought and rainfall patterns incongruent with grass species germination and establishment requirements (exacerbated by climate change) may adversely affect grassland health, and thus grassland breeding bird habitat. Future scenario models predicted increased temperatures and drought conditions (Butterfield and Munson 2016; Bunting et al. 2017).

Additionally, climatic variability in the Southwest may result in the loss of some cold-tolerant plant species and the subsequent species turnover to warm tolerant plant species (Gremer et al. 2015). As the effects of climate change continue, stability of the sandy geological substrates upon which many of PEFO grassland communities may become destabilized. Vegetation cover may be reduced prompting the shift of sand sheets and dunes by aeolian processes and potentially further exacerbating the loss of vegetation cover. This could result in increased airborne sediment, new dune formation, and actively moving dunes—similar to those that occur on the Navajo Nation, north of PEFO. Climate change scenario models for characteristic Southwestern plant species are currently under development and will ultimately be available to compare and assess vulnerable plant species at PEFO (K. Thomas, pers. comm. 2017).

Nonnative alien plant species decrease diversity and reduce fitness of native plants and have a negative ripple effect on higher trophic levels within the ecosystem (Vilà et al. 2011). In general, alien plant species are predicted to adversely affect arid vegetation communities due to: (1) a shifting regional climatic regime to a shorter freeze-free season supporting warm-tolerant annual grasses in the long term; (2) increased drought conditions providing favorable conditions for alien grass species expansion and colonization; and, (3) a longer fire season due to drier conditions, which increases fire probability in a given area and perpetuates a fire-alien plant species feedback loop (Abatzoglou and Kolden 2011). These shifts may ultimately reduce native plant species diversity, result in many alien plant species outcompeting native grassland species, and result in a vegetation community unsuitable for many vertebrate and invertebrate species. Within the 2003 park boundary, there are 21 nonnative alien plant species representing ~25% of the known grassland species (Hansen and Thomas 2006).

Presently, the NPS Southern Colorado Plateau Network, Inventory and Monitoring (SCPN, I&M) Program (DeCoster and Swan 2016) is monitoring 60 upland grassland plots to detect soil erosion, effects of climate change, and selected alien plant species. An additional and necessary component to this work should involve monitoring for alien plant species through annual surveys of disturbed areas and along roadsides. These data will be required to manage for and monitor established alien plant species populations, as well as serve as an early detection mechanism for newly colonizing alien plant species. In some cases, it may be possible to eradicate newly established alien plant species, which is why early detection is critical.

Although not specifically focused on grassland breeding bird species, van Riper et al. (2014) and Hatten et al. (2016) developed probabilistic distribution models of current and future ranges of selected bird species across the Southwestern United States; both identified distributional range contractions and shifts due to climate change. Specifically, Hatten et al. (2016) reported that across the bird species modeled, the more fragmented the species' current range, the greater the magnitude of habitat loss due to climate change. While no similar studies have been conducted to assess the effects of changing climate on the distributional ranges of grassland breeding birds, it is reasonable to suggest similar patterns will emerge. Modeling grassland bird distributional ranges should be considered as an important next step for understanding their current and future distributions, as well as using this information to guide future management decisions for PEFO grassland breeding birds.

To obtain comparative information on grassland bird populations in more pristine areas verses areas with alien plant species, a multiyear dataset should be acquired of study plots in both vegetation types. This would enable land managers to establish reference conditions of grassland breeding birds both within grasslands and in areas dominated by alien plant species, as well as potentially facilitate the development of models to predict future conditions in grasslands if alien plant species were to expand their distributional range(s) without removal and/or control.

As PEFO personnel plans to establish high densities of GPD with the goal as being selected for a black-footed ferret reintroduction site, monitoring the transition from small discontiguous GPD populations to higher population densities will be important in quantifying the changes on grassland plant species diversity and composition. To address this data gap, we recommend the establishment of a program to monitor the changes to grassland communities currently supporting GPD colonies. Methods for characterizing grasslands should follow and/or complement the methods applied by DeCoster et al. (2012), DeCoster and Swan (2016). The long-term desired condition for PEFO is to maintain healthy GPD populations in all suitable grassland habitats (Bridges, pers. comm., 2018). Prior to this occurring, baseline conditions (i.e., grassland community composition and percent vegetation cover of suitable habitat presently without GPD colonies) should be quantified. Additionally, detailed vegetation information for the 100 bird plots, with four subplots at each plot (total 400 vegetation sampling plots) was collected for grassland bird monitoring (J. Holmes, pers. comm. 2017); these data, as well as the data produced by the Southern Colorado Plateau Network (e.g., DeCoster et al. 2012; DeCoster and Swan 2016) may contain useful for characterizing baseline conditions, as well as to possibly evaluate potential GPD reintroduction sites.

Once GPD colonies have reached the desired condition, the resultant conditions should be quantified to establish an updated reference condition for PEFO grasslands with active GPD colonies. These grassland communities and the concordant percent vegetation cover will represent the reference condition to maintain. Additionally, prior to the GPD introductions into uncolonized areas, it would be advisable to obtain baseline grassland bird community data as well. While the SCPN bird monitoring is designed to measure the entire PEFO grassland bird community, site-specific bird data will be most accurate for both establishing a baseline of grassland breeding bird occurrence and abundance data. These surveys should be repeated annually to document any changes to community composition as GPD populations increase toward their desired conditions.

4.12.8. Sources of Expertise

- Jennifer Holmes, Colorado Plateau Research Station, Northern Arizona University, Flagstaff
- Andy Bridges, Petrified Forest National Park, National Park Service

4.13. Bats

4.13.1. Condition Summary

Condition assessment for bats provided in Table 4.13-1.

Table 4.13-1. Condition assessment summary for bats, Petrified Forest National Park, Arizona.

Indicator	Description	Condition Status/Trend	Summary
Bat species richness	10 species documented (Ruhl et al. 2003, Nowak and Emmons 2016)		Two studies using similar techniques PEFO known species. This baseline work is likely complete. Condition is considered "good," trend is probably "unchanging" and confidence in data is "high."
Summer roosts	One study conducted on pallid bats (Ruhl et al. 2003); no information on other species.		Give the limited information available (i.e., one study on pallid bats), condition, trend and confidence are unknown.
Hibernacula	Not known		No information is available regarding bat winter use; thus, condition, trend and confidence are unknown.

4.13.2. Background and Importance

At least nineteen bat species occur in northern Arizona (Hinman and Snow 2003). Of these, 10 species have been identified on PEFO during the breeding season (Ruhl et al. 2003, Nowak and Emmons 2016; Table 4.13-2). The Pallid bat (*Antrozous pallidus*) was the most commonly detected species by both Ruhl et al. (2003) and Nowak and Emmons (2016) at 83% (N = 256) and 68% (N = 34), respectively. Ruhl et al. (2003) radio tagged 13 pregnant or lactating *A. pallidus* females to locate 23 maternity roosts (five bats used multiple roosts) in rocky cracks, beneath rocks, holes in the ground and crevices in rim rock.

Table 4.13-2. Bats of Petrified Forest National Park from Ruhl et al. 2003 and Nowak and Emmons 2016.

Species	2003	2016
Pallid bat (*Antrozous pallidus*)	X	X
Townsend's big-eared bat (*Corynorhinus townsendii*)	X	X
Silver-haired bat (*Lasionycteris noctivagans*)	X	–
Big brown bat (*Eptesicus fuscus*)	–	X
California Myotis (*Myotis californicus*)	X	X
Western small-footed Myotis (*Myotis ciliolabrum*)	X	–
Fringed Myotis (*Myotis thysanodes*)	X	–
Long-legged Myotis (*Myotis volans*)	X	–
Yuma Myotis (*Myotis yumanensis*)	X	–
Canyon bat (*Parastrellus hesperus*)	X	–

4.13.3. Data and Methods

Only two bat studies have been conducted on PEFO (Ruhl et al. 2003, Nowak and Emmons 2016). Both studies employed mist-netting techniques and were concentrated primarily within dry washes. Ruhl et al. (2003) mist-netted for bats at nine sites primarily within dry washes near bridges between June and August 1998 and 1999. Additionally, Ruhl et al. (2003) radio tagged 13 pregnant or lactating *A. pallidus* females to characterize maternity roost selection at the park. Nowak and Emmons (2016) mist-netted bats at four sites between April and September during 2011 and 2012 by placing nets in proximity to abandoned and historic structures and/or along presumed flight corridors near the Puerco River; five bat species were detected during this study. Nowak and Emmons (2016) represented the first study of bats in the park expansion lands.

4.13.4. Reference Conditions

Ten bat species are known to occur within PEFO. Additionally, we have information on 23 *A. pallidus* maternity roosts. No information in available on habitat use or selection of any of these species beyond what is known in the primary literature. Thus, no reference conditions may be proposed for bat species known to occur within the park.

4.13.5. Conditions and Trend

Given the paucity of data concerning PEFO bats, it is not possible to suggest a trend for this resource. Thus, for bat diversity, as well as summer and winter roosts (McIntire 2010), the condition is "unknown/Indeterminate" and the trend is stated as "not assessed."

4.13.6. Threats, Issues, and Data Gaps

Data gaps include limited information on the 10 known bat species. Information exists for maternity roosts of *A. pallidus* and no information on maternity roosts of other bat species. Additionally, there is no information on hibernacula locations. Information on foraging habitat selection of PEFO bats is also lacking.

We recommend the following research be conducted to improve PEFO's knowledge of bat diversity, and winter and summer roost sites. (1) A GIS-based analysis should be conducted to identify rocky area, talus slopes, and possible subterranean features (caves and mines). Once areas have been identified, these areas should be surveyed and examined for roosting bats. (2) Conduct exit counts of the 23 *A. pallidus* maternity roosts identified by Ruhl et al. (2003). This should be done inexpensively using either night vision goggles and/or video camera with "nightshot"/ IR capabilities. (3) Survey all abandoned/historic buildings for roosting bats. We recommend conducting this work during the summer and winter months to identify the extent to which these human structures serve as maternity/bachelor roosts and/or hibernacula, respectively. (4) Establishing long-term monitoring sites for mist netting bats at the 13 sites originally sampled by Ruhl et al. (2003) and Nowak and Emmons (2016), as well as other appropriate monitoring locations (i.e., water tanks and other areas with standing water). Three sites should be sampled biennially. Given the large number, this could become part of an annual citizen-science program to sample for bats. Each summer, park personnel could sample half of the identified monitoring locations. These sites would be sampled every other year. (5) Establish long-term acoustic monitoring sites using the North American Bat Monitoring Program protocol (Loeb et al. 2015). Depending on personnel and time, a similar monitoring approach applied to mist-netting locations may be applied to monitoring bats using ultrasonic detectors.

4.13.7. Sources of Expertise

Andy Bridges, Petrified Forest National Park

4.14. Amphibians and Reptiles

4.14.1. Condition Summary

Condition summary for amphibians and reptiles provided in Table 4.14-1.

Table 4.14-1. Condition assessment summary for amphibians and reptiles, Petrified Forest National Park, Arizona.

Indicator	Description	Condition Status/Trend	Summary
Amphibian species richness	8 species (Drost et al. 1999, 2001; Nowak and Persons 2000; Nowak et al. 2007; Nowak 2002; Nowak and Hart 2002a; Nowak and Emmons 2016).		Multiple surveys over past 17 years convey "high" confidence regarding the completeness of this survey; thus, the condition is "good." As these populations are not presently being monitored, establishing a trend is not possible.
Reptile species richness	20 species (Drost et al. 1999, 2001; Nowak and Persons 2000; Nowak et al. 2007; Nowak 2002; Nowak and Hart 2002a, 2002b; Nowak and Emmons 2016).		Multiple surveys over past 17 years convey high confidence regarding the completeness of this survey; as these populations are not presently being monitored, establishing a trend is not possible.
Amphibian habitat extent	All available amphibian habitat has been identified (Drost et al. 1999; Nowak 2002; Nowak and Hart 2002a).		Drought and other disturbance events to impact standing water and edge habitats; climate change will exacerbate drought conditions; as the contraction and expansion of available amphibian habitat has not been monitored, condition and trend evaluations are "unknown"; however, confidence is "high" regarding where suitable habitat can and has occurred.

4.14.2. Background and Importance

Since 1999, amphibian and reptile surveys conducted on PEFO have ranged in both scope and geographic extent. Drost et al. (1999) conducted the first and only park-wide survey. Nowak and Persons (2000) and Nowak et al. (2007) focused on smaller geographic areas—Chinde Mesa and Rainbow Forest Wilderness Area, respectively. Three other studies (Nowak 2002; Nowak and Hart 2002a; Nowak and Hart 2002b), which did not identify any species not detect during previous, were narrowly geographic focused compliance projects. A total of eight amphibian and 20 reptile species (Table 4.14-2) are known to occur on Petrified Forest National Park (Drost et al. 1999, 2001; Nowak and Persons 2000; Nowak et al. 2007; Nowak 2002; Nowak and Hart 2002a, 2002b; Nowak and Emmons 2016). Collectively, these efforts identified one salamander, seven toads, 12 lizards, and eight snake species. None of these species represent "species of concern" or U.S. Fish and Wildlife Service "threatened" or "endangered" species.

Table 4.14-2. Eight amphibian and 20 reptile species, Petrified Forest National Park, Arizona. Based on Drost et al. 1999 (1), Nowak and Persons 2000, Nowak et al. 2007, Nowak 2002 (a), Nowak and Hart 2002 (b), Nowak and Hart 2002 (c), and Nowak and Emmons 2016.

Amphibian and Reptiles	Species	1999	2000	2007	2002 (a)	2002 (b)	2002 (c)	2016
Salamanders	Tiger salamander (*Ambystoma tigrinum*)	X	–	–	–	–	–	–
Toads	Couch's spadefoot (*Scaphiopus couchii*)	X	–	–	–	–	–	X
	New Mexico spadefoot (*Scaphiopus multiplicatus*)	X	–	–	–	–	–	–
	Southern spadefoot (*Spea multiplicata*)	–	–	X	X	–	X	X
	Plains spadefoot (*Spea bombifrons*)	X	–	–	–	–	X	X
	Great Plains toad (*Bufo cognatus*)	X	–	X	X	–	X	X
	Red-spotted toad (*Bufo punctatus*)	X	–	–	–	–	X	X
	Woodhouse's toad (*Bufo woodhousei*)	X	–	X	–	–	–	X
Lizards	Long-nosed Leopard Lizard (*Gambelia wislizenii*)	–	–	–	–	–	–	X
	Collared lizard (*Crotaphytus collaris*)	X	X	X	X	X	X	X
	Lesser earless lizard (*Holbrookia maculata*)	X	X	X	X	X	–	X
	Greater short-horned lizard (*Phrynosoma hernandesi*)	–	–	X	–	–	–	X
	Short-horned lizard (*Phrynosoma douglassii*)	X	–	–	–	–	–	–
	Sagebrush lizard (*Sceloporus graciosus*)	X	X	X	X	X	–	X
	Eastern fence lizard (*Sceloporus undulatus*)	X	X	X	X	X	X	–
	Plateau Fence Lizard (*Sceloporus tristichus)*	–	–	–	–	–	–	X
	Side-blotched lizard (*Uta stansburiana*)	X	X	X	X	X	X	X
	Little striped whiptail (*Aspidoscelis inornatus*)	X	–	–	–	–	–	–
	Plateau striped whiptail (*Aspidoscelis velox*)	X	X	X	X	X	X	X
	New Mexico whiptail (*Cnemidophorus neomexicanus*)	X	–	–	–	X	–	X
Snakes	Glossy snake (*Arizona elegans*)	X	–	X	–	–	–	X
	Night snake (*Hypsiglena torquata*)	X	–	X	–	–	–	X

Table 4.14-2 (continued). Eight amphibian and 20 reptile species, Petrified Forest National Park, Arizona. Based on Drost et al. 1999 (1), Nowak and Persons 2000, Nowak et al. 2007, Nowak 2002 (a), Nowak and Hart 2002 (b), Nowak and Hart 2002 (c), and Nowak and Emmons 2016.

Amphibian and Reptiles	Species	1999	2000	2007	2002 (a)	2002 (b)	2002 (c)	2016
Snakes (continued)	Common kingsnake (*Lampropeltis getulus*)	X	–	–	–	–	X	X
	Milk snake (*Lampropeltis triangulum*)	X	–	–	–	–	–	–
	Striped whipsnake (*Masticophis taeniatus*)	X	X	–	–	X	–	X
	Gopher snake (*Pituophis melanoleucus*)	X	X	X	X	X	–	X
	Prairie rattlesnake (*Crotalus viridis*)	X	–	–	–	–	–	–
	Hopi rattlesnake (*Crotalus viridis* var. *nuntius*)	–	X	X	X	–	X	–

4.14.3. Data and Methods

Twenty-six amphibians and reptiles are known to occur on Petrified Forest National Park. This information is based upon surveys prompted by six different projects spanning from 1999 through 2007 (Drost et al. 1999; Nowak and Persons 2000; Nowak 2002; Nowak and Hart 2002a; Nowak and Hart 2002b; Nowak et al. 2007).

4.14.4. Indicators & Measures

Indicator
Amphibian species richness and composition

Measures
Amphibian species richness and composition

Multiple surveys over past 17 years resulted in the identification of eight amphibian species (Drost et al. 1999; Nowak and Persons 2000; Nowak et al. 2007; Nowak 2002; Nowak and Hart 2002a; Nowak and Emmons 2016).

Indicator
Reptile species richness and composition

Measures
Reptile species richness and composition

Multiple surveys over past 17 years resulted in the identification of 20 reptile species (Drost et al. 1999; Nowak and Persons 2000; Nowak et al. 2007; Nowak 2002; Nowak and Hart 2002a, 2002b; Nowak and Emmons 2016).

Indicator
Amphibian habitat extent

Measures
Amphibian habitat extent

Like most other areas in the arid southwestern U.S., the presence of standing water during the breeding season is of the utmost importance for amphibians. Three areas where amphibians were observed successfully breeding include: (1) sites along the Puerco River; (2) backwater areas at the junctions of Dead and Ninemile Washes, and, (3) two ponds on old US Highway 180 at the south end of the park near the NPS horse corrals (Drost et al. 1999). The authors indicated the pond directly behind the horse corrals did not always contain sufficient water, while the large stock pond north of the corrals, was successful produced toadlets during both observational years. Park officials have confirmed there have been no changes or modifications to any of these breeding areas. Thus, these three areas likely remain important amphibian breeding habitats.

There were five other areas containing standing water during the breeding season but did not produce toadlets (Drost et al. 1999). These include: (1) borrow pit at mile marker 8 on the main road; (2) the alkaline flats between the Puerco Pueblo Ruins and the Puerco River; (3) low-lying areas along the main park road near old US Highway 180; (4) maintenance area west of Agate Bridge; and, (5) some of the backwater pools within small washes (e.g. Cottonwood, Jim Camp, and Dry Washes). Nowak (2002) and Nowak and Hart (2002a) further emphasized the importance of area between the escarpment at Puerco Pueblo and the Puerco River and the existing adjacent sewage ponds as critical habitats for breeding amphibians.

4.14.5. Reference Conditions

Reference conditions include both maintaining viable populations of the 26 amphibian and reptile species, and the three successful breeding areas for toads known to occur within the park boundary.

4.14.6. Conditions and Trend

Amphibian & reptile species richness: For both taxonomic groups, multiple surveys over past 17 years yield "high" confidence regarding the completeness of this survey; thus, the condition is "good." As these populations are not presently being monitored, establishing a trend is not possible.

Amphibian habitat extent: Drought and other disturbance events to impact standing water and edge habitats. Additionally, climate change will exacerbate drought conditions. As the contraction and expansion of available amphibian habitat has not been monitored, condition and trend evaluations are "unknown"; however, confidence is "high" regarding where suitable habitat can and has occurred.

4.14.7. Threats, Issues, and Data Gaps

Current threats include the reduction in habitat quality or potential loss of habitat where successful toad breeding occurs. Climate change models for the American Southwest predict decreased rainfall and a persistent drying trend resulting increased regional aridity throughout the 21st century (Seager et al. 2007; Cayan et al. 2010). These climatic changes are anticipated to adversely affect the ability for the known toad species to reproduce.

There are six data gaps where future research and monitoring should be considered. By addressing these research and monitoring topics, PEFO will improve their knowledge base of amphibians and reptiles, and may be able to improve the condition, trend, and confidence level associated with this natural resource. Topics to be further examined include the following.

1) Little striped whiptail (*Cnemidophorus inornatus*) – presently known from only two small areas in the park. This species may select for areas associated with prairie dog colonies and/or certain grassland/shrubland areas (Drost et al. 1999; Nowak et al. 2007).
2) New Mexico Whiptail Lizard (*Cnemidophorus neomexicanus*) was not previously known to NE Arizona, and its occurrence likely represents a human-induced nonnative species introduction (Drost et al. 1999). Although the population was previously identified as likely to be small (only two individuals were observed; Drost et al. 1999), it has displaced the little striped whiptail in human and livestock disturbed areas of New Mexico (Wright and Lowe 1993). It also has a tendency to rapidly colonize large areas (Densmore et al. 1989, Cuellar 1977). Thus, periodic surveys to monitor this species and the little striped whiptail is recommended. Drost et al. (1999) recommends monitoring this species within the Puerco River drainage.

3) Couch's spadefoot toad at PEFO may represent a relict population (Drost et al. 1999). Population census and monitoring of known breeding locations for this species will provide land managers with much needed information concerning population size and distribution of this species on PEFO.

4) Milk snake (*Lampropeltis triangulum*) – not recorded in Rainbow Forest Wilderness area. It was documented once south of Puerco River and at Agate Bridge (Nowak et al. 2007).

5) Prairie rattlesnake (*Crotalus viridis*) – Nowak et al. (2007) suggests there's a possibility this species range may extend westward into the park. If so, genetic analysis of PEFO individuals could contribute to ongoing studies on evolution and systematics of the Colorado Plateau Crotalus viridis species complex.

6) The last park-wide reptiles and amphibian survey was over 15 years ago. With the effects of climate change and increased human visitation to the park, we recommend another survey employing the same techniques and sampling the same areas as Drost et al. (1999). Such an effort will provide scientists and land managers with another critically important reference point for monitoring these taxonomic groups.

7) Available amphibian habitat should be spatially quantified, mapped, and monitored.

4.14.8. Sources of Expertise

- Andy Bridges, Petrified Forest National Park
- Erika Nowak, Colorado Plateau Research Station, Northern Arizona University

Chapter 5. Discussion

Of the 13 natural resources evaluated for the PEFO NRCA, air quality and the acoustic environment are identified as being moderate to significant and significant concern, respectively. Importantly, two resources (geology and paleontology, and grassland birds) are considered to be in “good to moderate” condition, eight re largely considered to be in good condition, and one resource (soil biocrusts) could not be evaluated due to insufficient information (Table 5.1-1).

Although the 13 natural resource elements have been thoroughly evaluated in the preceding pages, these elements are collapsed into four broad categories landscape, geology, vegetation, and wildlife for gap analysis. The aim is to succinctly highlight where additional research/ data collection is required to best manage resources on PEFO. For each of the four groups, data gaps are summarized, project ideas proposed, and resource(s) addressed by each proposal or project idea are identified.

Table 5.1-1. Condition assessment summary of the most important natural resources identified during the August 2015 scoping workshop, Petrified Forest National Park.

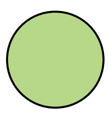
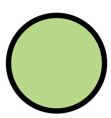
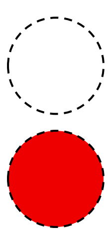
Resource	Overall Condition	Overall Condition Discussion
Viewshed		Viewsheds are an important part of the visitor experience at national monuments and parks, and features on the visible landscape influence a visitor’s appreciation and understanding of a particular region. PEFO structures within the human “built” environment are designed to complement the painted desert landscape. Currently, minimal development exists outside the park boundary, but PEFO has no jurisdiction concerning future development outside of the park. Overall, however, the monument’s current viewshed is good and confidence is medium. Trend could not be determined at this time.
Night Sky		Retaining dark night sky conditions is important for protecting the wilderness character of PEFO. In 2018, the park was designated an International Dark Sky Park. Designation was based upon two years of measurements. Overall current condition is good, and confidence is high given the data was recently collected. No reference conditions were available because of the short duration of the dataset; thus, trend could not be determined.
Acoustic Environment		In general, our ability to appreciate the solitude of the natural environment is becoming increasingly rare. In national parks and monuments, anthropogenic sounds not only negatively impacts the visitor experience, but also wildlife behavior and survival. Percent time audible for anthropogenic sound for “good condition” was exceeded in all but one case; as “moderate” to “significant” concern levels have not been established, this measure is unknown. Percent reduction in listening area when sound was recorded is of “significant concern.” Given the brief duration of time in which the data was collected (16 days in summer, 28 days in winter), overall confidence is low.

Table 5.1-1 (continued). Condition assessment summary of the most important natural resources identified during the August 2015 scoping workshop, Petrified Forest National Park.

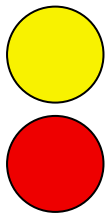
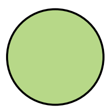
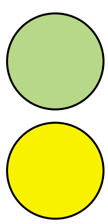
Resource	Overall Condition	Overall Condition Discussion
Air quality		Air quality impacts are related to both the air we breathe and the overall impact on ecosystems. As with most national park lands, PEFO air quality is influenced by activities located outside its boundary. Haze, ozone levels for human health, and wet deposition of nitrogen are of moderate concern. Ozone levels for vegetation are of “significant” concern, and deposition of sulfur are in “good condition.” Given the duration of the dataset (~4 years; 2011–2015), confidence is high’. Trend ranges from improving for haze and wet deposition of sulfur to unchanging for ozone, ozone for vegetation health and wet deposition of nitrogen. Because these vary, no trends are provided here.
Riparian		Riparian areas are limited to the Puerco River drainage. The nine vegetation classes comprising this riparian area once contained tamarisk. However, the tamarisk beetle has been present within the park since 2016 (RiversEdge West 2017), and Tamarisk has been removed in the past. Although condition presently unchanging, climate change may negatively impact native riparian areas in the future. Trend is unknown, and confidence is “medium” as monitoring of this species in riparian areas is needed.
Geology & Paleontology		(1) Persistent erosional processes continue to affect paleontological deposits; however, managers know where most deposits exist and routinely monitor the effects of erosion in these areas. Condition is considered “good” and trend seems to be improving. The information represents a 110 year dataset, confidence that the data is up-to-date is “high.” (2) No effective measures have been developed to prevent/deter petrified wood theft, nor is there a viable method to prevent it in the future exist. (3) Erosional impacts in bentonite areas is a problem for infrastructure and managers have an ongoing cyclic maintenance program to monitor and mitigate these impacts. Concern for further erosion is “moderate”; as the extent of areas susceptible are known, the trend is largely “unchanging” and confidence in the data is “high.” (4) All buildings and roads, especially those at Painted Desert Inn and the Blue Mesa loop should continue to be monitored. Concern for future impacts due to erosion is “moderate”; as the extent of areas susceptible are known, the trend is largely “unchanging” and confidence in the data is “high.” (5) Managers and geologists know the extent of the potash deposit; currently, no mining is underway. Although the potash deposit in the Holbrook Basin (which extends beneath park lands) is not presently being mined, this could change if there is an upturn in potash demand and mining the deposit becomes economically viable. Concern for future impacts related to mining is “moderate”; as the extent of the area to be impacted is known, the trend is largely “unchanging” and confidence in the data is “high.”

Table 5.1-1 (continued). Condition assessment summary of the most important natural resources identified during the August 2015 scoping workshop, Petrified Forest National Park.

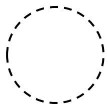
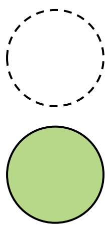
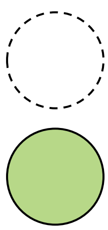
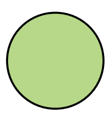
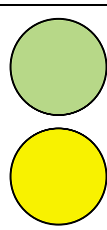
Resource	Overall Condition	Overall Condition Discussion
Damage to soil crusts		Cryptobiotic soils assist with nutrient cycling, water filtration, reduction in soil evaporation rates and increased soil stability. Erosion may be the greatest impact to soil biocrusts, although additional localized impacts include damage by human visitors venturing off established trails and pedestrian ways and occasional rogue cattle entering the park boundary. No estimates are available for percentage of soil crust land cover, nor has there been surveys to establish a baseline; thus, condition, trend and confidence is “unknown.”
Grasslands		(1) As the extent of grasslands are known and these systems are not currently being directly impacted by human activities, the condition is “good.” Changes in extent and species composition will likely to occur due to climate change; however, presently, trend is “unchanging.” As the extent of grasslands is well documented, confidence is “high.” (2) Native grassland species richness and composition condition is considered “good” with the trend “unchanging” and confidence “high.” (3) Alien plant species occurrence (in grasslands) appear limited to road corridors and developed areas. A study is needed to map current distributions and manage existing species and detect/ eradicate newly colonizing species. Thus, condition, trend, and confidence is “unknown.” (4) Ratio of native to alien plant species was 63 to 21; however, surveys have not been conducted in over a decade. This ratio may have changed with newly colonizing alien species.
Alien plant species		(1) Within the park, four alien plant species are ranked “high,” while 12 have “medium” ranking (AWIPWG 2005). Monitoring is needed for these 16 species/ (2) Change in percent cover of alien plant species is not known. No monitoring and/or geospatial data is available. (3) Distribution of alien species is not known. (4) Recovery of tamarisk-treated areas is not known, although the tamarisk beetle has been present within the park since 2016, and it has been effectively removed in the past.
Gunnison’s prairie dog		(1) Colony extent consists of 13 colonies comprising ~340 acres. While the GPD population has fluctuated since 1997 (and likely before), colony numbers are likely to increase given active management strategies to promote a healthy and stable population. (2) Available suitable habitat is 185,828 acres. Changes in precipitation patterns due to climate change may ultimately result in changes to the extent of suitable habitat.
Grassland birds		(1) Habitat extent is ~16,640 ha for the pre-expansion lands; no estimates exist within the expansion lands. (2) Native grassland bird species richness and composition is 41 grassland bird species within the pre-expansion boundary. No data within park expansion lands exists, but richness and composition is expected to be similar. (3) Seven indicator species occur within PEFO, and all were identified as in decline.

Table 5.1-1 (continued). Condition assessment summary of the most important natural resources identified during the August 2015 scoping workshop, Petrified Forest National Park.

Resource	Overall Condition	Overall Condition Discussion
Bats		(1) 10 bat species are known to occur within PEFO. (2) Only one study has been conducted to examine summer roosting of pallid bats; no information is available on other species. (3) Bat hibernacula within the park boundary is unknown.
Amphibians and reptiles		(1) Eight amphibians are known from PEFO. (2) Reptile species richness is 20 species. Multiple surveys over past 17 years convey high confidence regarding the completeness of this survey; as these populations are not presently monitored, establishing a trend is not possible. (3) Amphibian habitat extent is known. However, drought and other disturbance events may adversely affect standing water and edge habitats, and climate change is expected to exacerbate drought conditions.

5.1. Landscape Resources

While it is possible to manage natural resources that occur within the jurisdictional boundaries of national parks and monuments, the NPS is significantly challenged in their ability to safeguard landscape-scale resources, including viewsheds, night sky, soundscapes, and air quality. The conditions of these resources are largely to entirely influenced by anthropogenic activities occurring outside NPS boundaries. Because of this, partnerships for preservation will be critical for maintaining or improving landscape-scale conditions. Thus, such partnerships should be explored and established.

Primary landscape-scale threats to the PEFO's landscape-scale resources are: (1) degradation of the viewscape by potential future potash mining outside the park boundary; (2) diminished dark sky quality due to light pollution from growing population centers such as Flagstaff; (3) increasing noise pollution resulting due to increased vehicular traffic within the park; and, (4) smog and ozone levels produced from distant metropolitan areas including Phoenix and Los Angeles.

For viewscape, the NPS (or in collaboration with a third-party land conservation organization) may consider securing the mineral rights to the Holbrook potash deposit. Alternatively, because the deposit is several hundred feet below the Chinle Formation, it may ultimately be possible to access the deposit without the need for open pit surface mining within the expanded boundaries.

Aside from working with local municipalities (e.g., the Flagstaff City Council), little can be done to reduce the sky glow of Flagstaff and other growing towns. Given that PEFO does have a dark skies program, discussing the importance of reducing outside residential lighting should be done, but is unlikely to assist in reducing the proximal effects of sky glow from surrounding cities and towns.

To address the growing noise pollution problem within PEFO, park officials may wish to explore the development of an alternative transportation system (ATS), in particular, an electric shuttle bus program. Electric shuttle buses would greatly reduce vehicular traffic noise within the park, and given the majority of daylight hours is cloud free, a solar power station could be developed to fuel the buses.

Shuttle bus programs are increasingly common on NPS lands. At least 50 national parks (including Zion, Acadia, Sequoia and Kings Canyon, Grand Canyon, Mount Rainier, Yosemite, and Rocky Mountain National Parks) have ATS (Daigle 2008). As with several national parks, Yosemite NP has a fleet of electric-hybrid buses that operate daily (White et al. 2011), while Zion NP has been experimenting with retrofitting their gas bus fleet with electric engines (Wadsworth 2018). Thus, advocating for silent electric shuttle buses from the outset may not be viewed as unreasonable.

Gaps to be addressed for landscape-scale resources include additional sampling for both the acoustic environment and monitoring of dark sky conditions within the park boundary.

1) For the acoustic environment, data was collected for 16 days during summer and 28 days in winter at one frontcountry and one backcountry site. Expanding this study to examine other areas, as well as increasing sampling intensity would provide the more robust dataset needed to make a stronger case for proposing noise mitigation strategies (which could include an electric shuttle bus program).
2) As sky glow from surrounding municipalities is expected to intensify in the future, data from a monitoring program would be an effective tool for working with local governments to help reduce these effects.

5.2. Geology

Paleontological resources are the most important geological resource within the park. One of the biggest problems with the protection of these resources is the unlawful removal of petrified wood. Unfortunately, there have been no effective measures developed to prevent or deter theft, nor is there a viable method to prevent it in the future. This is the largest gap for geological resources. Additional research (perhaps focus group research) should be explored to identify reasonable measures to prevent petrified wood theft.

5.3. Vegetation

Vegetation resources include grasslands, riparian areas, alien plant species and soil biocrusts. The extent of grasslands has been quantified within the 2003 park boundary and an approximately 1 km buffer outside this park boundary (Hansen and Thomas 2006; Thomas et al. 2009a). Although the types of riparian communities have been documented within PEFO, a paucity of data exists for the invasive tamarisk tree within these riparian areas, the distributions and occurrences of alien plant species in general, and the distribution of soil biocrusts.

Gaps for vegetation resources include the following:

1) A geospatial vegetation analysis for the expansion lands, tantamount to Thomas et al. (2009a), should be conducted. This will serve to identify grassland extent and characterization of grassland communities within these lands. A groundtruthing effort to confirm model predictions should be include and may be used to obtain grassland species richness data.

2) Although the tamarisk beetle was confirmed within the park in 2006 and mechanical removal of tamarisk has occurred in the past, no removal and monitoring program exists. To fill this data gap, routine mechanical removal, as well as monitoring the effects of tamarisk beetle on tamarisk should be implemented.
3) Currently, the park lacks a nonnative alien plant species removal and monitoring program. This will be required to both manage for established alien plant species, as well as for early detection of newly colonizing species.
4) No information exists on the occurrence and distribution of cryptobiotic soils. A baseline study is needed.

Note: For alien plants and cryptobiotic soils, inventory and monitoring projects should be conducted parkwide (i.e., in both the 2003 park boundary and expansion lands).

5.4. Wildlife Resources

Park managers consider the most important wildlife resources to be Gunnison prairie dogs, grassland birds, bats, and amphibians and reptiles. Within the 2003 park boundary, Gunnison prairie dogs (GPD) and grassland birds have been well-studied and monitored. Efforts are underway to establish viable and stable GPD colonies so that black-footed ferrets may be introduced into the park. The GPD monitoring program is active, and the park is making strides toward this goal. A long-term grassland bird community study has been underway since 2007 (refer to Holmes and Johnson 2010, 2012, 2014, 2016).

Data gaps for wildlife resources include the following:

1) While the grassland bird community is expected to be similar within the 2003 park boundary and expansion lands, the current monitoring program should ultimately be expanded to include the park expansion lands. This work should similarly assess the condition of indicator species within this area.
2) Aside from one bat presence/ absence study (Nowak and Emmons. 2016) and a summer roost study of pallid bats (Ruhl et al. 2003), little is known regarding bat natural history within the park. Importantly, managers do not know where most of the bats are roosting during the summer, nor do they know where hibernacula roosts occur within the park. With the westward advance of white-nose syndrome (WNS; refer to WNSRT 2019), understanding bat distributions within the park may be vital to managing for cave and crevice-roosting bat species once WNS arrives in Arizona.
3) Although multiple surveys for reptiles and amphibians have been conducted within the 2003 park boundary over past 17 years, no research has been conducted in the expansion lands. While the community is expected to be similar, the park should aim for a compete survey to obtain a more complete picture concerning the distributions of herptofauna within the entire park boundary.

5.5. Anthropogenic Climate Change

Natural resources and ecosystem processes are highly dynamic. Importantly, understanding the effects of anthropogenic climate change and decoupling these effects from other human activities can be challenging. However, increased temperature and drought due to anthropogenic climate change will result in changes to resource conditions in the American Southwest (e.g., Seager et al. 2007; Cayan et al. 2010). Identifying sound practices to mitigate for these impacts, within an adaptive management framework, will be required to best manage PEFO's natural resources into the future. In general, anthropogenic climate change will result in increased temperatures, a decrease in the average number of days below freezing, and increased drought conditions. PEFO's Foundation Document (NPS 2015) intimates the following impacts due to climate change driven increased summer temperature, storm frequency and/or severity and droughts:

- Increased erosion rates and exposure of paleontological and archaeological resources;
- Archeological sites that are not stabilized may be further negatively impacted;
- More days with temperatures exceeding 95 degrees F (during the summer) may change park visitation patterns;
- Increased temperatures during the summer will have significant impacts on water resources (e.g., ponds, springs, and the Puerco River), species composition, and habitat that support a range of biological resources;
- Impacts associated with nonnative alien plant species (e.g., tamarisk, yellow star thistle) occurrence and distribution will be magnified;
- Significant impacts to contemporary facilities and associated park operations including potential increases in nonnative alien plant species, erosion, and reduced water resources for park operations (e.g., potable water supplies); and,
- Negative impacts on wilderness and scenic values.

While many of the effects of anthropogenic climate change are already upon us, we do not know how intensely resources will respond, nor do we know how the effects of anthropogenic climate change will interact with other human activities (e.g., pollution, landscape conversion, habitat fragmentation, etc.). Importantly, the impacts to species and wilderness at PEFO was discussed in a general sense. However, the IPCC (2014) states that "many species will be unable to track suitable climates under mid- and high-range rates of climate change during the 21st century ([with] medium confidence). Lower rates of change will pose fewer problems. Some species will adapt to new climates. Those that cannot adapt sufficiently fast will decrease in abundance or go extinct in part or all of their ranges." Figure 5.5-1 is a comparison of maximum speeds that species can disperse across landscapes (based on observations and models; vertical axis on left) to the speeds with which temperatures are expected to move across landscapes (climate velocities for temperature; vertical axis on right). It should be noted that these responses will be affected by and interplay with other human activities. Although these dispersal speeds verses temperature changes are based upon coarse taxonomic groups, this information may be generalized to understand how organisms may respond to increased average temperatures at PEFO.

Unfortunately, most parks (including PEFO) lack the information necessary to model how climate change will impact their natural resources. Thus, the PEFO Foundation Document (NPS 2015) was able to capture, in a general sense, the resources likely to be most impacted. Through effective monitoring, we are hopeful that park managers will be able to make effective decisions within an adaptive management paradigm. Importantly, park personnel working with park visitors should aspire to stay current with the evidence-based information on climate change and aim to effectively and credibly communicate this information to the general public. This will be critically important as anthropogenic climate change will increasingly affect all aspects of resources, operations, and visitor experiences within U.S. National Parks and Monuments (Monahan and Fisichelli 2014).

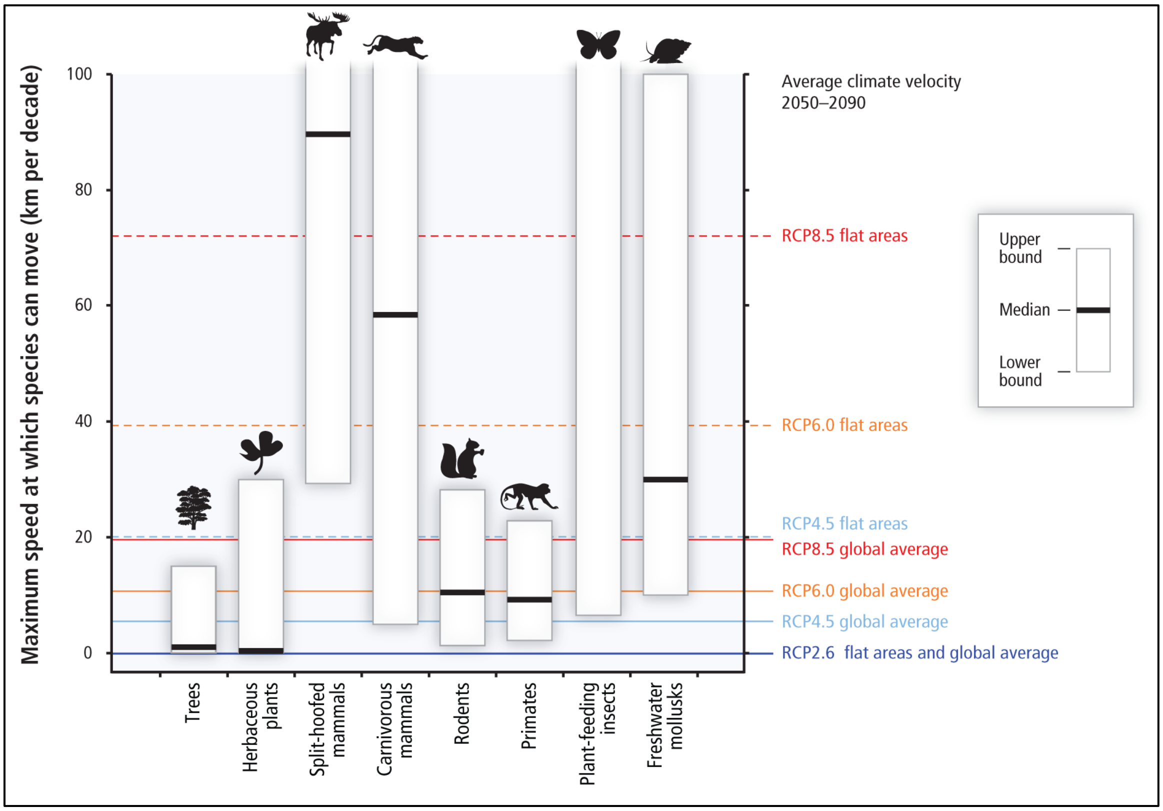


Figure 5.5-1. White boxes with black bars indicate ranges and medians for maximum movement speeds of selected species. These speeds are based on observational data and models (vertical axis on left) and depict how these organisms may disperse to suitable habitat, compared to speeds with which temperatures are projected to move across landscapes (climate velocities for temperature; vertical axis on right). Representative Concentration Pathways (i.e., RCP 2.6, 4.5, 6.0, and 8.5) for 2050–2090 are horizontal lines showing climate velocity for the global-land-area average and for large flat regions. Species with maximum speeds below each line are expected to respond to climatic warming without human intervention (IPCC 2014).

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Appendix A. Bortle Dark-sky Scale

Table A-1. Bortle Dark-sky scale for gauging light pollution (Bortle 2001). Classes range from 1 (best conditions) through 9 (worst conditions). Title was assigned by Bortle to describe either viewing conditions or proximity to different types of human population centers. NELM (naked-eye limiting magnitude), while considered a poor criterion, still aids in parameterizing Bortle's nine classes. Sky brightness or magnitude is provided in measurements of one arc second ($mag/arcsec^2$). Description provides a summary of sky conditions and objects viewable (or not) in the night sky.

Class	Title	NELM	Brightness	Description
1	Excellent dark-sky site	7.6–8.0	21.7–22.0	• Zodiacal light visible and colorful • Gegenschein, zodiacal band and sky glow visible • Scorpius and Sagittarius regions of the Milky Way cast obvious shadows • Many constellations, particularly fainter ones, barely recognizable due to the large number of stars • Many Messier and globular clusters naked-eye objects • Galaxy M33 is a naked-eye object • Limiting magnitude with 12.5" reflector is 17.5 (with effort)
2	Typical truly dark site	7.1–7.5	21.5–21.7	• Zodiacal light distinctly yellowish and bright enough to cast shadows at dusk and dawn • Sky glow may be weakly visible near horizon • Clouds only visible as dark holes against the sky • Surroundings barely visible silhouetted against the sky • Summer Milky Way highly structured • Many Messier objects and globular clusters are naked-eye objects • Galaxy M33 easily seen with naked eye • Limiting magnitude with 12.5" reflector is 16.5
3	Rural sky	6.6–7.0	21.3–21.5	• Zodiacal light striking in spring and autumn, color is still visible • Some light pollution evident at horizon • Clouds illuminated near horizon, dark overhead • Nearby surroundings vaguely visible • Summer Milky Way appears complex • Galaxies M15, M4, M5, and M22 are naked-eye objects • M33 easily visible with averted vision • Limiting magnitude with 12.5" reflector is 16

Class	Title	NELM	Brightness	Description
4	Rural/ suburban transition	6.1–6.5	20.4–21.3	• Zodiacal light still visible, but does not extend halfway to the zenith at dusk or dawn • Light pollution domes visible in several directions • Clouds illuminated in the directions of the light sources, dark overhead • Surroundings clearly visible, even at a distance • Milky Way well above the horizon is still impressive, but lacks detail • M33 is a difficult averted vision object, only visible when high in the sky • Limiting magnitude with 12.5" reflector is 15.5
5	Suburban sky	5.6–6.0	19.1–20.4	• Only hints of zodiacal light seen on the best nights in autumn and spring • Light pollution visible in most, if not all, directions • Clouds noticeably brighter than the sky • Milky Way very weak or invisible near the horizon, and looks washed out overhead • At half-moon (first/last quarter) in a dark location the sky appears like this, but with the difference that the sky appears dark blue • Limiting magnitude with 12.5" reflector is 15
6	Bright suburban sky	5.1–5.5	18.0–19.1	• Zodiacal light invisible • Light pollution makes the sky within 35° of the horizon glows grayish white • Clouds anywhere in the sky appear fairly bright • Even high clouds (cirrus) appear brighter than the sky background • Surroundings are easily visible • Milky Way only visible near the zenith • M33 not visible, M31 modestly apparent • Limiting magnitude with 12.5" reflector is 14.5
7	Suburban/ urban transition	4.6–5.0	18.0–19.1	• Light pollution makes entire sky light gray • Strong light sources evident in all directions • Clouds brightly lit • Milky Way invisible • Galaxies M31 and M44 may be glimpsed, but with no detail • Through a telescope, the brightest Messier objects are pale ghosts of their true selves • At full moon in a dark location the sky appears like this, but with the difference that the sky appears blue • Limiting magnitude with 12.5" reflector is 14

Class	Title	NELM	Brightness	Description
8	City sky	4.1–4.5	<18.0	• Sky light gray or orange—one can easily read • Stars forming familiar constellation patterns may be weak or invisible • M31 and M44 are barely glimpsed by an experienced observer on good nights • Even with telescope, only bright Messier objects can be detected • Limiting magnitude with 12.5" reflector is 13
9	Inner-city sky	4.0	<18.0	• Sky brilliantly lit • Many stars forming constellations are invisible and many fainter constellations are invisible • Aside from the Pleiades, no Messier object is visible to the naked eye • The only objects to observe are the Moon, the planets, and a few of the brightest star clusters

Appendix B. Geospatial Sound Model (LA_{50})

Maps depicting median natural and existing sound levels of the geospatial sound model (LA_{50} Zero Impact), Petrified Forest National Park, Arizona (from Mennitt et al. 2014)(Figures B-1 and B-2).

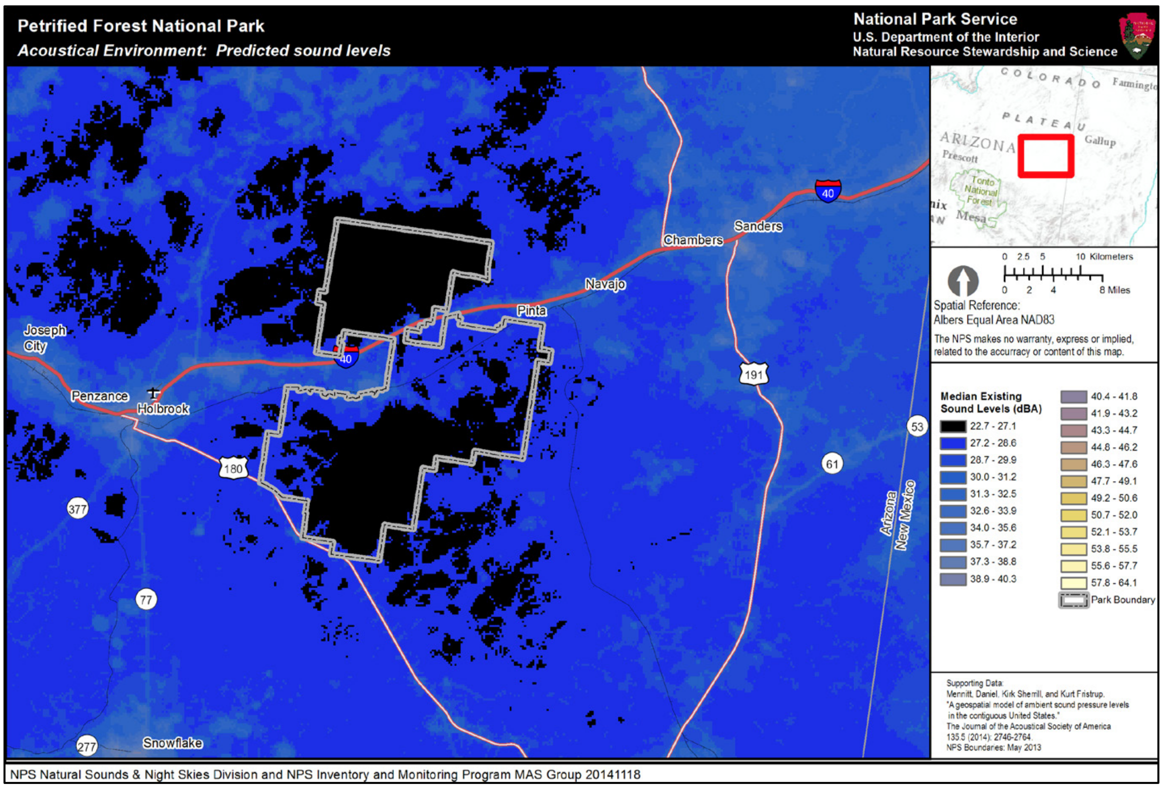

Figure B-1. Median natural sound pressure levels generated using version 3.0 of the geospatial model, Petrified Forest National Park, Arizona (Wood 2015). Color scale indicates the decibel level predicted in the park based on natural sound sources only. Sound level is measured in A-weighted decibels (dB). Black and dark blue colors indicate low decibel levels gradating from lighter blue to yellow indicate higher decibel levels.

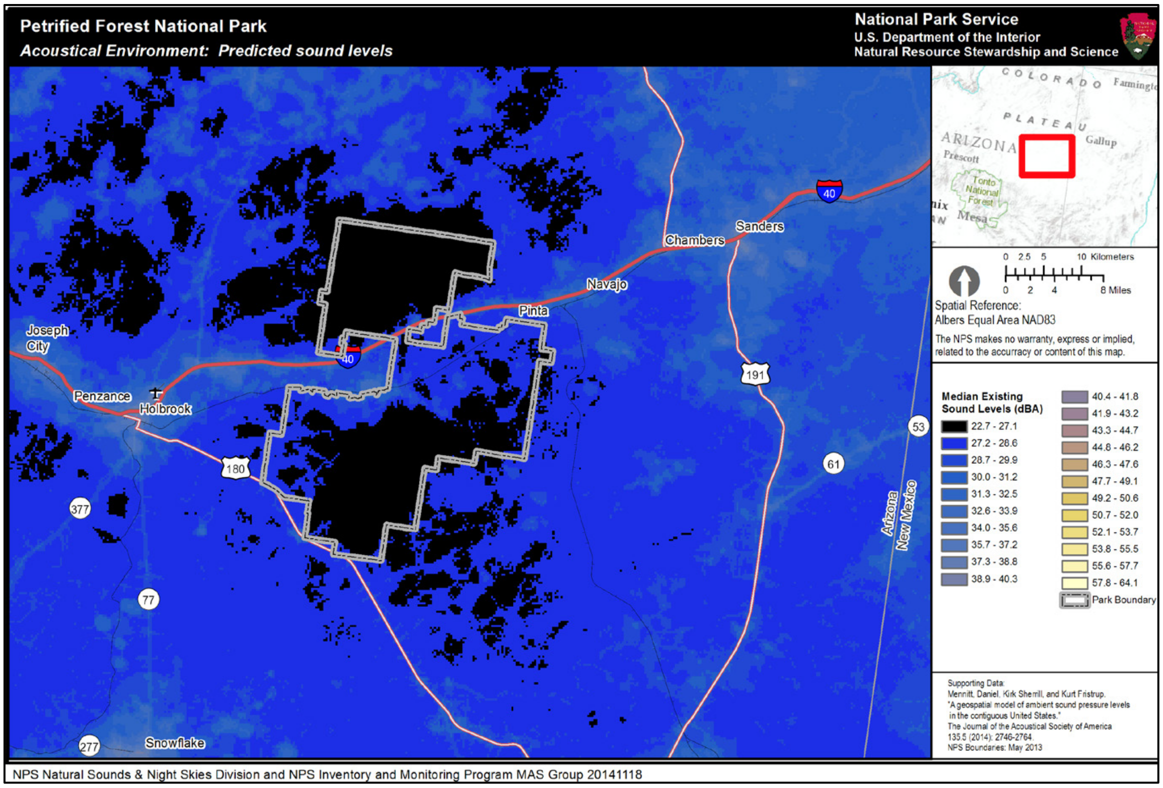

Figure B-2. Median existing sound pressure levels generated using version 3.0 of the geospatial model, Petrified Forest National Park, Arizona (Wood 2015). Color scale indicates the decibel level predicted in the park based only on both human-caused and natural sound sources. Sound level is measured in A-weighted decibels, or dB. Black and dark blue colors indicate low decibel levels gradating to lighter blue to yellow indicating higher decibel levels.

Appendix C. Riparian Plant Species

Table C-1. Annotated list of 11 native and 2 alien riparian species, Petrified Forest National Park, Arizona. Developed from Thomas et al. (2009) and K. Thomas (pers. com. 2018).

Species Name	Authority	Common Name
Calamovilfa gigantea	(Nutt.) Scribn. & Merr.	Giant sandreed, big sandreed
Chrysothamnus depressus	Nutt.	Longflower rabbitbrush; Dwarf rabbitbrush
Chrysothamnus greenei	(A.Gray) Greene	Greene's rabbitbrush
*Elaeagnus angustifolia**	L.	Russian olive; Oleaster
Ericameria nauseosa	(Pall. ex Pursh) G.L.Nesom & G.I.Baird	Goldenbush
Ericameria nauseosa ssp. *nauseosa* var. *nauseosa*	(Pall. ex Pursh) G.L.Nesom & G.I.Baird	Rubber rabbitbush
Forestiera pubescens var. *pubescens*	–	New Mexico forestiera
Lorandersonia pulchella	(A. Gray) Urbatsch, R.P. Roberts & Neubig	Southwest rabbitbrush
Populus fremontii	S. Watson	Cottonwood
Salix exigua	Nutt.	Coyote willow
Sporobolus cryptandrus	(Torr.) A. Gray	Sand dropseed
*Tamarix chinensis**	Lour.	China tamarisk
Typha domingensis	Pers.	Southern cattail

* Alien species

Appendix D. List of Paleontological Species

Linnaean taxonomy of Late Triassic animals, plants, and trace fossils of Petrified Forest National Park (*version August 15, 2018*)

*Bold denotes the most precise level of identification possible to date. Holotype specimens from lands that are now within the park boundary are designated with a ♦♦. Probable new species are designated with a *. Palynomorph taxa are designated with a ♣.*

Kingdom Animalia
Phylum Chordata
Subphylum Vertebrata
Class Chondrichthyes
Subclass Elasmobranchii
Superorder Euselachii
Order Xenacanthida
Family Xenacanthidae
Xenacanthus moorei

Order Ctenacanthiformes
Superfamily Hybodontoidea
Family Hybodontidae
Subfamily Polyacrodontidae
Lonchidion humblei

Subfamily Acrodontidae
Reticulodus synergus

Class Osteichthyes
Subclass Actinopterygii

Order Saurichthyiformes
Family Saurichthyidae
Saurichthys sp.

Order Perleidiformes
Family Perleididae
Perleididae sp.

Family Colobodontidae
Colobodontidae sp.

Order Redfieldiiformes
Family Redfieldiidae
cf. *Lasalichthys* sp. 1

Lasalichthys sp. 2

Order Semionotiformes
Family Semionotidae
Semionotidae sp.

Infraclass Chondrostei
Order Palaeonisciformes
Suborder Palaeonisciformes
Family Palaeoniscidae
cf. *Turseodus* sp. 1
Turseodus sp. 2

Infraclass Holostei
Order Dapediiformes
Family Dapediidae
Hemicalypterus weiri

Class Sarcopterygii
Subclass Actinistia
Order Coelocanthiformes
Family Mawsoniidae
Genus *Chinlea* sp.

Subclass Dipnoi
Order Ceratodontiformes

Family Arganodontidae
Arganodus sp.

Superclass Tetrapoda
Class Amphibia
Subclass Temnospondyli
Infraorder Trematosauria
Superfamily Metoposauroidea
Family Metoposauridae
Apachesaurus gregorii

Koskinonodon perfectus

Subclass Lissamphibia
Order Anura*
Class Amniota
Genus *Kraterokheirodon colberti*♦♦

Subclass Sauropsida
Infraclass Parareptilia
Family Procolophonidae
Colognathus obscurus

Infraclass Eureptilia
Acallosuchus rectori♦♦

Palacrodon browni

Family Drepanosauridae
Superorder Testudinata
Parvclass Lepidosauromorpha
Superorder Lepidosauria
Order Rhynchocephalia
Suborder Sphenodontia
Family Sphenodontidae*
Sphenodontidae sp.

Order Squamata*
Parvclass Archosauromorpha
Uatchitodon schneideri

Family Tanystropheidae

Order Allokotosauria
Family Trilophosauridae
Teraterpeton sp.

Trilophosaurus buettneri
Trilophosaurus dornorum♦♦

Family Azendohsauridae
Malerisaurus sp.*

Minclass Archosauriformes
Ankistrodon sp.*

Crosbysaurus harrisae

Vancleavea campi♦♦

Family Doswelliidae
Doswellia kaltenbachi

Suborder Phytosauria
Family Phytosauridae

Subfamily Leptosuchomorpha
Pravusuchus hortus

Proteme batalaria♦♦

Smilosuchus adamanensis♦♦
Smilosuchus gregorii
Smilosuchus lithodendrorum♦♦

Tribe Pseudopalatinae
Machaeroprosopus buceros
Machaeroprosopus jablonskiae♦♦
Machaeroprosopus mccauleyi♦♦
Machaeroprosopus pristinus♦♦

Superorder Archosauria
Order Pseudosuchia
Suborder Suchia
Infraorder Aetosauriformes
Acaenasuchus geoffreyi

Family Revueltosauridae
Revueltosaurus callenderi
Revueltosaurus hunti

Superfamily Aetosauria
Family Stagonolepididae
Subfamily Aetosaurinae
Adamanasuchus eisenhardtae♦♦

Calyptosuchus wellesi

Scutarx deltatylus♦♦

Tribe Typothoracinae
Typothorax coccinarum

Subtribe Paratypothoracini
Paratypothorax sp.

Rioarribasuchus chamaensis

Tecovasuchus sp.

Subfamily Desmatosuchinae
Desmatosuchus spurensis

Superfamily Paracrocodylomorpha
Family Rauisuchidae
Postosuchus kirkpatrickorum

Subfamily Poposauridae
Poposaurus gracilis

Tribe Shuvosauridae
Shuvosaurus sp.*

Superfamily Crocodylomorpha
Family Sphenosuchidae
Hesperosuchus sp.*

Parrishia mccreai

Order Ornithodira
Suborder Pterosauria
Infraorder Rhamphorhynchoidea*
Suborder Dinosauromorpha
Family Silesauridae
Eucoelophysis baldwini

Minorder Dinosauria
Infraorder Saurishia
Parvorder Theropoda
Chindesaurus bryansmalli♦♦

Superfamily Coelophysoidea
Family Coelophysidae
Coelophysis sp.*

Subclass Synapsida
Order Therapsida
Suborder Theriodontia
Infraorder Cynodontia*
Cynodontia sp.

Suborder Anomodontia
Infraorder Dicynodontia
Parvorder Pristerodontia
Family Kannemeyeriidae
Placerias hesternus

Phylum Mollusca
Subphylum Diasoma

Class Bivalvia
Subclass Paleoheterodonta
Order Unionoida
Superfamily Unionidea
Family Unionidae
Plesielliptio altidorsalis♦♦
Plesielliptio arizonensis
Plesielliptio pictodesertis♦♦

Subfamily Hyriidae
Antediplodon acuodorsis♦♦
Antediplodon cristonensis
Antediplodon dockumensis
Antediplodon dumblei
Antediplodon gallinensis
Antediplodon graciliratus
Antediplodon terraerubrae
Antediplodon thomasi
Antediplodon torrentis♦♦
Antediplodon tenuiconchis♦♦

Subphylum Cyrtosoma
Class Gastropoda
Order Sorbeoconcha
Superfamily Cerithioidea
Family Pleuroceridae
Lioplacodes assiminoides
Lioplacodes canaliculatus
Lioplacodes latispira
Lioplacodes pilsbryi

Phylum Arthropoda
Subphylum Crustacea
Class Malacostraca
Subclass Eumalacostraca
Order Decapoda
Suborder Pleocyemata
Superfamily Erymoidea
Family Erymidae
Subfamily Eryminae
Enoploclytia porteri♦♦

Class Ostracoda
Class Branchiopoda

Subclass Phyllopoda
Order Conchostraca

Kingdom Plantae
Carpolithus chinleana♦♦

Cordaitina minor♣

Dictyophyllidites harrisii♣

Dinophyton spinosus♦♦

Colpectipollis ellipsoideus♣
Colpectipollis singulisinus♦♦♣

Cornetipollis reticulata♦♦♣

Froehlicksporites traversei♣

Klukisporites granosifenestellatus♦♦♣

Kulgerina meieri♣

Minutosaccus crenulatus♣

Osmundacidites welmanii♣

Pachysaccus ferroccidentalis♦♦♣

Piceapollenites orbatus♦♦♣

Plicatisaccus badius♣
Plicatisaccus segmentatus♦♦♣

Pramelreuthia yazzi♦♦

Protohaploxipinus triquetricorpus♦♦♣
Protohaploxipinus arizonicus♦♦♣

Rugubivesiculites proavitus♦♦♣

Samaropollenites sp.♣
Samaropollenites concinnus♦♦♣

Schizosaccus keuperi♣

Spencerites chinleana♦♦♣

Sulcatisporites kraeusli♣

Todisporites major♣

Tulesporites terraerubrae♦♦♣

Vitreisporites pallidus♣

Division Gnetophyta
Class Gnetopsida
Order Ephedrales
Family Ephedraceae
Ephedra chinleana♦♦♣

Division Pteridospermatophyta
Alisporites opii♦♦♣

Chordasporites chinleanus♣

Pityosporites oldhamensis♣
Pityosporites chinleana♦♦♣

Protodiploxypinus lacertosus♦♦♣

Class Lyginopteridopsida
Order Lyginopteridales
Family Lyginopteridaceae
Sphenopteris arizonica♦♦

Division Ginkgophyta
Class Ginkgoopsida
Order Ginkgoales
Family Ginkgoaceae
Baiera arizonica♦♦

Ginkgoites watsoni♦♦

Ginkgoxylpropinquus hewardii

Division Cycadophyta
Class Bennettitopsida
Order Bennettitales
Family Bennettitaceae
Otozamites powelli

Class Cycadopsida
Order Cycadales
Androcycas santucii♦♦

Aricycas paulae♦♦

Cycadospadix sp*

Marcouia neuropteroides♦♦

Pretricolpipollenite bharadwajii♣

Division Tracheophyta
Class Polypodiopsida
Order Hymenophyllales
Family Hymenophyllaceae
Hopetedia sp.*

Order Osmundales
Family Osmundaceae
Itopsidema vancleaveii♦♦

Todites fragilis♦♦

Order Schizaeles
Family Cynepteridaceae
Cynepteris bolichii♦♦
Cynepteris lasiophora♦♦

Division Pteridophyta
Order Equisetales
Family Equisetaceae
Equicalastrobus chinleana♦♦

Equisetites bradyi

Neocalamites virginiensis

Order Gleicheniales
Family Matoniaceae
Phlebopteris smithii♦♦

Order Cyatheales
Family Dicksoniaceae
Wingatea plumosa♦♦

Order Filicales
Family Dipteridaceae
Apachea arizonica♦♦

Cladophlebis daughertyi♦♦

Cladophlebis yazzia♦♦

Clathopteris walkeri♦♦

Division Pinophyta
Arboromosa semicircumtrachea♦♦

Pramelreuthia yazzi♦♦

Schilderia adamanica

Class Pinopsida
Order Voltziales
Daughertyspora chinleana♣

Enzonalasporites vigens♣

Klausipollenites lithodendrum♦♦♣
Klausipollenites gouldii
Var. Klausipollenites gouldii striatus♦♦♣

Patinasporites densus♣

Triadispora dockumensis♦♦♣
Triadispora fallax♦♦♣

Vallasporites ignacii♣

Voltziaceaesporites heteromorpha♣
Voltziaceaesporites globosus♦♦♣

Order Cordaitales
Family Cordaitaceae
Dadoxylon chaneyi♦♦

Pelourdea poleoensis

Samaropsis puerca♦♦

Order Pinales

Alostrobus traversei

Angustisaccus reniformes♦♦♣
Angustisaccus petulans♦♦♣

Araucariorhiza joae♦♦

Araucariacites sp.♣

Camerosporites sp.♣

Chinleoxylon knowltonii

Creberanthus bealeii♦♦

Crystalloxylon imprimicrystallus♦♦

Masculostrobus lafonii

Pullisilvaxylon arizonicum♦♦
Pullisilvaxylon daughertii♦♦

Silicisilvaxylon imprimicrystallus♦♦
Silicisilvaxylon secundacrystallus ♦♦

Woodworthia arizonica♦♦

Family Protopinaceae
Protopiceoxylon novum♦♦

Family Podocarpaceae
Podozamites arizonicus♦♦

Family Cheirolepidiaceae
Protocupressinoxylon arizonica♦♦

Family Araucariaceae
Auracarites rudicula♦♦

Brachyphyllum hegewaldi♦♦

Pagiophyllum simpsonii♦♦

Ichnotaxa
Apatopus sp.

Archeoentomichnus metapolypholeos♦♦

Kouphichinium arizonae♦♦

Paleoxyris humblei♦♦

Paleobuprestis maxima♦♦
Paleobuprestis minima♦♦

Paleoscolytus divergus♦♦

Paleoipidus perforatus♦♦

Paleoipidus marginatus♦♦

Polyporites wardii♦♦

Rhynchosauroides sp.

Appendix E. Annotated List of Grassland Plant Species

Table E-1. Annotated list of 63 native and 21 alien grassland species, Petrified Forest National Park, Arizona from Hansen and Thomas (2006).

Species Name	Authority	Common Name
Achnatherum aridum	(Jones) Barkworth	Mormon needlegrass
Achnatherum hymenoides	(Roemer & Schultes) Barkworth	Indian ricegrass
Achnatherum speciosum	(Trin. & Rupr.) Barkworth	desert needlegrass
*Agropyron desertorum**	(Fischer ex Link) Schultes	desert wheatgrass, fairway
Agrostis stolonifera	L.	creeping bentgrass, redtop
Andropogon gerardii	Vitman	big bluestem
Andropogon hallii	Hack	sand bluestem
Aristida adscensionis	L.	sixweeks threeawn
Aristida purpurea var. *longiseta*	(Steud.) Vasey	Fendler threeawn, purple threeawn
*Bothriochloa ischaemum**	(L.) Keng	yellow bluestem
Bothriochloa saccharoides	(Sw.) Rydb.	silver bluestem needle grama
Bouteloua aristidoides	(Kunth) Griseb.	needle grama
Bouteloua barbata	Lag.	sixweeks grama
Bouteloua curtipendula var. *curtipendula*	(Michx.) Torr.	sideoats grama
Bouteloua eriopoda	(Torr.) Torr	black grama
Bouteloua gracilis	(Willd. ex Kunth) Lag ex Griffiths	blue grama
Bouteloua hirsute	Lag.	hairy grama
Bouteloua rothrockii	Vasey	Rothrock's grama
Bouteloua simplex	Lag.	matted grama
*Bromus diandrus**	Roth	ripgut brome
Bromus hordeaceus ssp. *hordeaceus**	L.	soft brome, soft chess
*Bromus inermis**	Leyss.	smoothe brome, Hungarian brome
*Bromus japonicus**	Thunb. ex Murr.	Japanese brome
*Bromus rubens**	L.	foxtail brome, red brome
*Bromus tectorum**	L.	cheat grass
Calamovilfa gigantean	(Nutt.) Scribn. & Merr.	giant sandreed
Cenchrus spinifex	Cav.	coastal sandbur
Chloris virgate	Sw.	feather fingergrass
*Cynodon dactylon**	(L.) Pers.	Bermuda grass
Dasyochloa pulchella	(Kunth) Willd.	low woollygrass, fluffgrass
Distichlis spicata	(L.) Greene	inland saltgrass, desert saltgrass
*Echinochloa crus-galli**	(L.) Beauv.	barnyardgrass

Species Name	Authority	Common Name
Elymus elymoides ssp. *elymoides*	(Raf.) Swenzy	wildrye, squirreltail
Elymus x *pseudorepens*	(Scribn. & Sm.) Barkworth & Dewey	false quackgrass
Enneapogon desvauxii	Beauv.	nineawn pappusgrass, spike pappusgrass
*Eragrostis barrelieri**	Daveau	Mediterranean lovegrass
Eragrostis intermedia	Hitchc.	plains lovegrass
Eragrostis Mexicana	(Hornem.) Link	Mexican lovegrass
Eragrostis pectinacea	(Michx.) Nees ex Steud	tufted lovegrass
Eragrostis spectabilis	(Pursh) Steud.	purple lovegrass
Hesperostipa comata var. *comata*	(Trin. & Rupr.) Barkworth	needle and thread grass
Hesperostipa neomexicana	(Thurb. ex Coult.) Barkworth	New Mexico feathergrass
Hordeum jubatum	L.	foxtail barley
Hordeum murinum ssp. *leporinum**	(Link) Arcang.	leporinum barley, rabbit barley
Hordeum pusillum	Nutt.	little barley
Leptochloa fusca ssp. *fascicularis*	(Lam.) Snow	bearded sprangletop
*Lolium perenne**	L.	perennial ryegrass
*Lolium pretense**	(Huds.) Darbyshire	meadow ryegrass
Muhlenbergia depauperate	Scribn.	sixweeks muhly
Muhlenbergia longiligula	Hitchc.	longtongue muhly
Muhlenbergia porteri	Scribn. ex Beal	bush muhly
Muhlenbergia pungens	Thurb.	sandhill muhly
Muhlenbergia torreyi	(Kunth.) Hitchc. ex Bush	ring muhly
Munroa squarrosa	(Nutt.) Torr.	false buffalograss
Panicum capillare	L.	witchgrass
Panicum hirticaule	Presl	Mexican panicgrass
Panicum obtusum	Kunth	obtuse panicgrass, vine mesquite
Pascopyrum smithii	(Rydb.) Love	western wheatgrass
*Pennisetum glaucum**	(L.) Br.	pearl millet
Phragmites australis	(Cav.) Trin. ex Steud.	common reed
Piptatherum micranthum	(Trin & Rupr.) Backworth	smilograss
Pleuraphis jamesii	Torr.	James' galleta
Poa arida	Vasey	plains bluegrass
Poa fendleriana	(Steud.) Vasey	muttongrass
Poa pratensis	L.	Kentucky bluegrass
*Polypogon monspeliensis**	(L.) Desf.	annual rabbitsfoot grass
*Polypogon viridis**	(Gouan) Breistr.	beardless rabbitsfoot grass
*Puccinellia distans**	(Jacq.) Parl.	weeping alkaligrass

Species Name	**Authority**	**Common Name**
Puccinellia fasciculate	(Torr.) Bickn.	saltmarsh alkaligrass, Torrey alkaligrass
Puccinellia nuttalliana	(Schultes) Hitchc.	Nuttall's alkaligrass
Schedonnardus paniculatus	(Nutt.) Trel.	tumblegrass
Schizachyrium scoparium ssp. *Neomexicaum*	(Nash) Gandhi & Smeins	New Mexico little bluestem
Scleropogon brevifolius	Phil.	burrograss
*Setaria viridis**	(L.) Beauv.	green bristlegrass
*Sorghum halepense**	(L.) Pers.	Johnsongrass, millet
Sporobolus airoides	(Torr.) Torr.	alkali sacaton
Sporobolus contractus	Hitchc.	spike dropseed
Sporobolus coromandelianus	(Retz.) Kunth.	Madagascar dropseed
Sporobolus cryptandrus	(Torr.) Gray	sand dropseed
Sporobolus flexuosus	(Thurb. ex Vasey) Rydb.	mesa dropseed
Sporobolus giganteus	Nash	giant dropseed
Sporobolus interruptus	Vasey	black dropseed
*Thinopyrum ponticum**	(Podp.) Liu & Wang	tall wheatgrass
Vulpia octoflora var. *hirtella*	(Piper) Henr.	sixweeks fescue

* Alien species

Appendix F. Annotated List of Alien Plant Species

Table F-1. The 67 known invasive alien plant species from Petrified Forest National Park, Arizona. “Type” refers to the vegetation type—forb, grass, or tree. “Family,” “Species name,” species’ “authority,” and “common name” are provided. “Notes” indicates further information on the invasive species including previous synonymy. “Authors” to the source documenting the occurrence of the species: Hansen 1998 (1), Hansen and Thomas 2006 (2), DeCoster and Swan 2009 (3), DeCoster et al. 2012 (4), DeCoster and Swan 2016 (5), and Thomas et al. 2009 (6). Taxonomy was validated using the Integrated Taxonomic Information System (www.itis.gov), accessed 08/2017. “Rank” is classified into four categories developed by AWIPWG (2005). (1) **High**: Species had severe impacts on ecosystems, plant and animal communities, and vegetation structure; invasiveness was conducive to moderate to high rates of dispersal and establishment; and, species were typically widely distributed, both among and within ecosystems/communities. (2) **Medium**: Species had substantial and apparent impacts on ecosystems, plant and animal communities, and vegetation structure; invasiveness was conducive to moderate to high rates of dispersal, often enhanced by disturbance; and, ecological amplitude (diversity of ecosystems/communities) and distribution (within an ecosystem/community) ranged from limited to widespread. (3) **Low**: Species had minor yet detectable ecological impacts; invasiveness resulted in low to moderate rates of invasion; and, ecological amplitude and distribution was generally limited, but the species could be problematic locally. (4) **Evaluated but not listed**: Current information was inadequate to categorize the species in one of the above three categories. A “–” indicates species not appearing on the AWIPWG (2005).

Type	Family	Species Name	Authority	Common Name	Notes	Authors	Rank
Forbs	Amaranthaceae	*Atriplex rosea*	L.	tumbling saltweed	–	1	–
	Amaranthaceae	*Corispermum hyssopifolium*	L.	common bugseed	–	1	–
	Amaranthaceae	*Halogeton glomeratus*	(Bieb.) Mey.	saltlover	–	5	–
	Amaranthaceae	*Kochia scoparia*	(L.) Schrad.	burningbush	–	1, 5	–
	Amaranthaceae	*Salsola collina*	Pall.	slender Russian thistle	–	5	2
	Amaranthaceae	*Salsola kali*	L.	Russian thistle	*Salsola kali* spp. *tragus* (6); *Salsola kali* (1)	1, 6	–

[1] Species was not in itis.gov database; thus, taxonomy could not be validated.

[2] Hrusa and Gaskin (2008) suggest this species is now considered to occur only in coastal areas. All *S. kali* on the Colorado Plateau are probably *S. tragus* or one of the complex described by Hrusa and Gaskin (2008) (K. Thomas, pers. com. 2017).

[3] Hansen (1998) questioned whether identification was correct. However, DeCoster et al. (2012) also detected this species, which may provide additional support for Hansen’s (1998) earlier identification.

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Type	Family	Species Name	Authority	Common Name	Notes	Authors	Rank
Forbs (cont’d)	Amaranthaceae	*Salsola tragus*	L.	prickly Russian thistle	Hrusa and Gaskin (2008) suggest this may be 1 of a 3 species complex (S. tragus, S. gobicola, and S. paulsenii).	3, 5, 6	2
	Asteraceae	*Rhaponticum repens*	(L.) Hidalgo	Russian knapweed	*Acroptilon repens* (Fischer ex Link) J.A.	1	–
	Asteraceae	*Carduus nutans*	L.	nodding plumeless thistle	–	4	2
	Asteraceae	*Cirsium vulgare*	(Savi) Ten.	bull thistle	–	1	3
	Asteraceae	*Helianthus ciliaris*	DC.	Texas blueweed	–	1	–
	Asteraceae	*Lactuca serriola*	L.	prickly lettuce	–	1	–
	Asteraceae	*Persicaria lapathifolia*	(L.) Gray	curlytop knotweed	*Polygonum lapathifolium* L.	1	–

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Type	Family	Species Name	Authority	Common Name	Notes	Authors	Rank
Forbs (cont'd)	Asteraceae	*Sonchus asper*	(L.) Hill	spiny sowthistle	–	1, 6	2
	Asteraceae	*Taraxacum officinale*	Wigg.	common dandelion	–	4	–
	Asteraceae	*Tragopogon dubius*	Scop.	yallow salisfy	Not certain on ID (1)	1, 4	–
	Asteraceae	*Tragopogon pratensis*	L.	Jack-go-to-bed-at-noon	–	1	–
	Asteraceae	*Xanthium strumarium*	L.	rough cocklebur	–	1	–
	Boraginaceae	*Lappula occidentalis* var. *cupulata*	*L. occidentalis* (Watson) Greene, *cupulata* (Gray) Higgins	flatspine stickweed	–	1	–
	Brassicaceae	*Lepidium chalepensis*	L.	lens-podded whitetop	–	1	–
	Brassicaceae	*Descurainia sophia*	(L.) Webb ex Prantl	herb sophia	–	4	–

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Type	Family	Species Name	Authority	Common Name	Notes	Authors	Rank
Forbs (con'd)	Geraniaceae	*Erodium cicutarium*	(L.) L'Hér. ex Aiton	redstem stork's bill	May represent a native invasive species	1, 4, 5, 6	2
	Lamiaceae	*Marrubium vulgare*	L.	horehound	–	1	–
	Molluginaceae	*Mollugo cerviana*	(L.) Ser.	threadstem carpetweed	–	5	–
	Plantaginaceae	*Plantago lanceolata*	L.	narrowleaf plaintain	–	1	–
	Plantaginaceae	*Plantago major*	L.	common plaintain	–	1	–
	Portulacaceae	*Portulaca oleracea*	L.	common purslane	–	1, 3, 5	–
	Ranunculaceae	*Ranunculus testiculatus*	Crantz	curveseed buttercup	*Ceratocephala testiculata* (Crantz) Roth	1, 4	–
	Scrophulariaceae	*Verbascum blattaria*	L.	moth mullein	–	1	–
	Simaroubaceae	*Ailanthus altissima*	(Mill.) Swingle	tree-of-heaven	–	1	–

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Forbs?	Scrophulariaceae	*Verbascum thapsus*	L.	mullein	–	1	4
	Zygophyllaceae	*Tribulus terrestris*	L.	pucturevine	–	1	4
Grasses	Poaceae	*Agropyron cristatum*	(L.) Gaertn.	crested wheatgrass	–	1	–
	Poaceae	*Agropyron desertorum*	(Fisch. ex Link) Schult.	desert wheatgrass	–	2	–
	Poaceae	*Bromus didandrus*	Roth	ripgut brome	Not in itis.gov	1, 2	–
	Poaceae	*Bromus hordeaceus* ssp. *hordeaceus*	L.	soft brome	–	1, 2	–
	Poaceae	*Bromus inermis*	Leyss.	smoothe brome	–	2	2
	Poaceae	*Bromus japonicus*	Thunb. ex Murr.	Japanese brome	–	2	–
	Poaceae	*Bromus rubens*	L.	red brome	–	1, 2, 6	1
	Poaceae	*Bromus tectorum*	L.	cheatgrass	–	1, 2, 3, 4, 5, 6	1

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Type	Family	Species Name	Authority	Common Name	Notes	Authors	Rank
Grasses (cont'd)	Poaceae	*Cynodon dactylon*	(L.) Pers.	bermuda grass	–	1, 2	2
	Poaceae	*Echinochloa crus-galli*	(L.) Beauv.	barnyardgrass	–	2	3
	Poaceae	*Enneapogon desvauxii*	Beauv. ex Desv.	nineawn pappusgrass	–	5	–
	Poaceae	*Thinopyrum ponticum*	(Podp.) Liu & Wang	tall wheatgrass	–	1	–
	Poaceae	*Eragrostis barrelieri*	Daveau	Mediterranean lovegrass	–	1, 2	–
	Poaceae	*Hordeum murinum* ssp. *leporinum*	(Link) Arcang.	rabbit barley	*Hordeum murinum* ranked as 2	2	–
	Poaceae	*Hordeum jubatum*	L.	foxtail barley	–	6	–
	Poaceae	*Lolium perenne*	L.	perennial ryegrass	–	1, 2	3
	Poaceae	*Schedonorus pratensis*	(Huds.) Beauv.	meadow fescue	–	1	–

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[2] Hrusa and Gaskin (2008) suggest this species is now considered to occur only in coastal areas. All *S. kali* on the Colorado Plateau are probably *S. tragus* or one of the complex described by Hrusa and Gaskin (2008) (K. Thomas, pers. com. 2017).

[3] Hansen (1998) questioned whether identification was correct. However, DeCoster et al. (2012) also detected this species, which may provide additional support for Hansen's (1998) earlier identification.

Table F-1 (continued). The 67 known invasive alien plant species from Petrified Forest National Park, Arizona. "Type" refers to the vegetation type—forb, grass, or tree. "Family," "Species name," species' "authority," and "common name" are provided. "Notes" indicates further information on the invasive species including previous synonymy. "Authors" to the source documenting the occurrence of the species: Hansen 1998 (1), Hansen and Thomas 2006 (2), DeCoster and Swan 2009 (3), DeCoster et al. 2012 (4), DeCoster and Swan 2016 (5), and Thomas et al. 2009 (6). Taxonomy was validated using the Integrated Taxonomic Information System (www.itis.gov), accessed 08/2017. "Rank" is classified into four categories developed by AWIPWG (2005). (1) **High**: Species had severe impacts on ecosystems, plant and animal communities, and vegetation structure; invasiveness was conducive to moderate to high rates of dispersal and establishment; and, species were typically widely distributed, both among and within ecosystems/communities. (2) **Medium**: Species had substantial and apparent impacts on ecosystems, plant and animal communities, and vegetation structure; invasiveness was conducive to moderate to high rates of dispersal, often enhanced by disturbance; and, ecological amplitude (diversity of ecosystems/communities) and distribution (within an ecosystem/community) ranged from limited to widespread. (3) **Low**: Species had minor yet detectable ecological impacts; invasiveness resulted in low to moderate rates of invasion; and, ecological amplitude and distribution was generally limited, but the species could be problematic locally. (4) **Evaluated but not listed**: Current information was inadequate to categorize the species in one of the above three categories. A "–" indicates species not appearing on the AWIPWG (2005).

Type	Family	Species Name	Authority	Common Name	Notes	Authors	Rank
Grasses (cont'd)	Poaceae	*Cenchrus americanus*	(L.) Morrone	pearl millet	*Pennisetum glaucum* (L.) R. Br.	2	–
	Poaceae	*Polypogon monspeliensis*	(L.) Desf.	annual rabbitsfoot grass	–	1, 2, 6	–
	Poaceae	*Polypogon viridis*	(Gouan) Breistr.	beardless rabbitsfoot grass	*Polygonum viridis* (Gouan) Breistr.	1, 2	–
	Poaceae	*Polygonum aviculare* var. *salicifolium*	–	prostrate buckwheat	Not in itis.gov	1, 3, 5	–
	Poaceae	*Puccinellia distans*	(Jacq.) Parl.	weeping alkaligrass	–	1, 2	–
	Poaceae	*Setaria viridis*	(L.) Beauv	green bristlegrass	–	1, 2	–
	Poaceae	*Sorghum halepense*	(L.) Pers.	Johnsongrass	–	1, 2	2
	Poaceae	*Thinopyrum ponticum*	(Podp.) Barkworth & Dewey	tall wheatgrass	–	2, 5	–

[1] Species was not in itis.gov database; thus, taxonomy could not be validated.

[2] Hrusa and Gaskin (2008) suggest this species is now considered to occur only in coastal areas. All *S. kali* on the Colorado Plateau are probably *S. tragus* or one of the complex described by Hrusa and Gaskin (2008) (K. Thomas, pers. com. 2017).

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Table F-1 (continued). The 67 known invasive alien plant species from Petrified Forest National Park, Arizona. "Type" refers to the vegetation type—forb, grass, or tree. "Family," "Species name," species' "authority," and "common name" are provided. "Notes" indicates further information on the invasive species including previous synonymy. "Authors" to the source documenting the occurrence of the species: Hansen 1998 (1), Hansen and Thomas 2006 (2), DeCoster and Swan 2009 (3), DeCoster et al. 2012 (4), DeCoster and Swan 2016 (5), and Thomas et al. 2009 (6). Taxonomy was validated using the Integrated Taxonomic Information System (www.itis.gov), accessed 08/2017. "Rank" is classified into four categories developed by AWIPWG (2005). (1) **High**: Species had severe impacts on ecosystems, plant and animal communities, and vegetation structure; invasiveness was conducive to moderate to high rates of dispersal and establishment; and, species were typically widely distributed, both among and within ecosystems/communities. (2) **Medium**: Species had substantial and apparent impacts on ecosystems, plant and animal communities, and vegetation structure; invasiveness was conducive to moderate to high rates of dispersal, often enhanced by disturbance; and, ecological amplitude (diversity of ecosystems/communities) and distribution (within an ecosystem/community) ranged from limited to widespread. (3) **Low**: Species had minor yet detectable ecological impacts; invasiveness resulted in low to moderate rates of invasion; and, ecological amplitude and distribution was generally limited, but the species could be problematic locally. (4) **Evaluated but not listed**: Current information was inadequate to categorize the species in one of the above three categories. A "–" indicates species not appearing on the AWIPWG (2005).

Type	Family	Species Name	Authority	Common Name	Notes	Authors	Rank
Herbaceous vine	Convolvulaceae	*Convolvulus arvensis*	L.	field bindweed	–	1	2
Shrubs	Brassicaceae	*Sisymbrium altissimum*	L.	tall tumblemustard	–	1, 4, 6	–
	Elaeagnaceae	*Elaeagnus angustifolia*	L.	Russian olive	–	1, 6	1
	Fabaceae	*Medicago sativa*	L.	alfalfa	–	1	–
	Fabaceae	*Melilotus officinalis*	(L.) Lam.	sweetclover	–	1	2
	Fabaceae	*Alhagi maurorum*	Medik.	camelthorn	–	1	2
	Fabaceae	*Bothriochloa ischaemum*	(L.) Keng	yellow bluestem	–	2	–
Shrubs?	Solanaceae	*Solanum elaeagnifolium*	Cav.	silverleaf nightshade	–	1	–
Trees	Tamaricaceae	*Tamarix chinensis*	Lour.	five-stamen tamarix	–	1, 6	1
	Ulmaceae	*Ulmus pumila*	L.	Siberan elm	–	1	2

[1] Species was not in itis.gov database; thus, taxonomy could not be validated.

[2] Hrusa and Gaskin (2008) suggest this species is now considered to occur only in coastal areas. All *S. kali* on the Colorado Plateau are probably *S. tragus* or one of the complex described by Hrusa and Gaskin (2008) (K. Thomas, pers. com. 2017).

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Appendix G. Detection Frequencies of Grassland Bird Species

Table G-1. Mean number of individuals detected per variable circular plot count (with standard deviation provided in parentheses), mean plot frequency (% of plots per cluster in which the species was detected) for grassland and aridland indicator bird species, Petrified Forest National Park, AZ (Holmes and Johnson 2010, 2012, 2014, 2016).

	2007		2009		2012		2015	
Grassland bird species	**Mean # detected (SD)**	**Mean Plot Freq. (%)**	**Mean # detected (SD)**	**Mean Plot Freq. (%)**	**Mean # detected (SD)**	**Mean Plot Freq. (%)**	**Mean # detected (SD)**	**Mean Plot Freq. (%)**
Black-throated sparrow	1.22 (0.94)	79	1.49 (0.95)	78	1.38 (0.97)	80	1.79 (0.81)	96
Eastern meadowlark	0.4 (0.4)	57	0.42 (0.37)	50	0.25 (0.33)	36	1.65 (0.81)	93
Western meadowlark	0.32 (0.43)	53.8	0.06 (0.09)	12	0.21 (0.29)	30	0.76 (0.84)	63
Scaled quail	0.52 (0.4)	73	0.12 (0.19)	15	0.01 (0.02)	2	0.22 (0.37)	25
Cassin's sparrow	0.23 (0.54)	23	0.02 (0.03)	3	0.04 (0.09)	5	0.02 (0.06)	3
Vesper sparrow	–	–	0.01 (0.02)	1	0.02 (0.03)	3	–	–
Lark bunting	–	–	–	–	–	–	0.06 (0.13)	9

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